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GEOLOGICAL RELATIONS OF THE NORTH AFRICAN IRON ORES.

PER GEIJER.

THE economic importance of the iron ore deposits in French and Spanish North Africa is widely known, but their geological relations have not attracted much attention except among those who have been most directly concerned with their exploitation. The following attempt at a survey is based on the existing literature—almost entirely by French authors when French territory is concerned, and by Spanish authors for the Spanish zone in northern Morocco [1]—and on impressions from a journey, undertaken in 1926 under the joint auspices of the Geological Survey of Sweden and the Jernkontoret. The particular object in sight was to study the relations between ore-forming replacement on one hand and stratigraphy and structure of the replaced rock on the other, in the hope that in this way some light might be shed upon the geological history of certain ore deposits in Sweden. Thanks to the courteous aid extended by geologists and mining men alike, the author was enabled to carry out this program, and also to see so much of the general geology of the deposits that he dares to attempt this summary.

GENERAL GEOLOGY.

The iron-ore-bearing region of North Africa includes Algeria and Tunisia north of the Sahara, and the eastern part of the

[1] The literature referred to in the following is listed at the end of the paper. For Algeria, the work by Dussert is particularly important, while that by Berthon furnishes a counterpart for Tunisia.

Spanish zone in northern Morocco. The outcropping rocks are Mesozoic and Tertiary sediments, except in a zone near the Mediterranean coast, where there is a chain of massifs of Pre-Cambrian and Paleozoic rocks. Triassic sediments are exposed in many places, but only as small areas, and are represented by limestones, marls, much gypsum and some rock salt. The Liassic is represented by limestones that are often ore-bearing and always very conspicuous in the landscape by forming steep mountains. It is mainly restricted to a zone near the coast. The Jurassic has a somewhat wider distribution. Only in Spanish Morocco do rocks that are regarded as Jurassic come in contact with iron ore deposits. The Cretaceous and the Eocene, again, form an almost or entirely concordant sedimentary series of very wide distribution, largely made up of marls and limestones. The Oligocene is represented mainly by continental sediments, but the Miocene shows a renewed wide extension of the sea over this region.

The whole region belongs to the Tertiary orogenetic belt of the Mediterranean. There have been traced at least two phases of folding movements, one that has affected the Mesozoic sediments and the Eocene, and one later phase, of Miocene to Pliocene age. The folds strike S.W.–N.E. or W.S.W.–E.N.E., and control the morphological development of the Atlas mountain system.

Igneous rocks are inconspicuous. Mesozoic "ophites" are seen in the Triassic. Tertiary granites and intrusions of other types are met with in certain portions of the coast zone, and were probably connected with the earlier Tertiary folding. Other displays of igneous activity are represented by volcanic piles and shallow intrusions, mainly of an andesitic character, that are conspicuous elements in the Miocene of some parts of the coast zone. There are also locally basaltic volcanoes referred to the Pleistocene or the Upper Pliocene. All these later manifestations of volcanism seem to have been caused by the later Tertiary folding and the great subsidences that formed its last phase. At greater distances from the coast, only certain still active thermal springs may be interpreted as signs of igneous activity.

TYPES OF ORE DEPOSITS.

Among the iron ores of this region, several geologically different types are represented (see Fig. 1). Most important is one

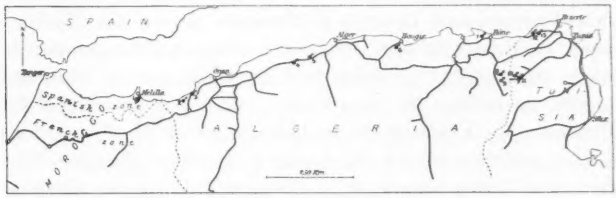

FIG. 1. Key map, showing position of important iron ore deposits in North Africa, and railroad system. 1 Beni Bu Ifrur, with Monte Uixan, 2 Rar el Maden, 3 Beni Saf, 4 Rouina, 5 Zaccar, 6 Timezrit, 7 Mokta el Hadid, 8 Ouenza, 9 Bou Kadra, 10 Slata, 11 Djerissa, 12 Nefzas, 13 Douaria.

that may be termed the Bilbao type: replacement deposits, originally carbonate (siderite) but now oxidized to hematite. To this type belong practically all the now producing mines in Algeria, and Djerissa and Slata in Tunisia. Two other types are also of present economic importance: the hematite layers of northern Tunisia (Douaria and Nefzas), recently interpreted by Berthon and Solignac as sediments of Miocene age, and the magnetite-hematite deposits of Monte Uixan and vicinity in Morocco, which belong to the contact type. Formerly, a considerable amount of magnetite ore was produced from ore bodies in Pre-Cambrian limestone west of Bône, but the leading mine in that group, Mokta el Hadid, is now exhausted. Oolitic ores of sedimentary origin are reported from some places, but are not worked so far, and are little known. The following geological descriptions are restricted to the deposits of the Bilbao type, and a comparison with Monte Uixan.

PRODUCTION, AND ORE RESERVES

A few figures may serve to illustrate the actual and potential importance of these deposits. The iron ore production of Al-

geria and Tunisia in 1925 is estimated to about 1,770,000 and 723,000 metr. tons respectively, almost all of it being of Bessemer grade, and the average iron content probably near 55 per cent. Ouenza is the leading producer in Algeria, with Beni Saf second, while Djerissa and Douaria predominate among the Tunisian mines. Official estimates of the ore reserves have resulted in figures from 30 to 75 million tons, or possibly much more for Ouenza, 22 million for Bou Kadra, and about 20 million for Djerissa. The Uixan group in Morocco produced 280,000 tons in 1925, and the total for the district was around 380,000. The reserves of Uixan seem to be of the same order of magnitude as those of Ouenza.

THE AFRICAN REPRESENTATIVES OF THE BILBAO TYPE.

These form two geographical groups, one scattered in the coast zone, from the Morocco-Algeria frontier eastwards to E. of Bougie, and the other occupying an inland region around the boundary between Algeria and Tunisia. The former group occurs in Liassic limestone, the other in a limestone of Aptian age (Lower Cretaceous). The general character of the ores is practically always the same. Originally the ore mineral was siderite, probably often sprinkled with pyrite. The siderite is locally found intact in some mines when the water level is reached, and a large body is reported by Dussert to occur on the lower levels of the Rar el Maden mine, where also much pyrite was found with it. Generally, however, the ore that is exposed in the mine workings is oxidized and consists of dull bluish hematite. Nevertheless, the original sideritic nature is often apparent, for the crystalline structure of the siderite may be splendidly preserved. This variety corresponds entirely to the "campanil" ore of Bilbao. While it seems clear that the texture in question may occur also where the oxidation of the carbonate has been complete, the writer has found that some specimens that were studied microscopically still contain a considerable percentage of siderite. There are frequently seen vugs, coated with siderite crystals, now transformed into hematite. Often a second generation of siderite coats these oxidized crystals of the older cavity lining.

Limonite seems to be almost entirely lacking in some of the larger deposits. In others there is a moderate quantity, mostly mixed with the hematite. Crusts and reniform aggregates of limonite, the type of the "rubio" ore of Bilbao, are rarely conspicuous. The only mine where the writer noted them in any amount was Timezrit near Bougie. They are said to be largely restricted to the uppermost parts and the sides of this deposit (which outcrops with only some smaller projections); the rest is the ordinary hematite, although in part with limonite veins.

Hematite of presumably primary origin was observed in some of these deposits. A finely micaceous form occurs locally with the ore of Zaccar, or independently as thin veins in the limestone (similar material was noted by the writer in the neighborhood of Cartagena in Spain). At Beni Saf, some coarse specular hematite was seen at the margins of an ore body.

The iron percentage in these ores averages about 55. The content of manganese generally varies between 1 and 2 per cent., rarely rising up to 10 per cent. or more (locally in some of the westernmost mines). Phosphorus is low, almost all the ore being of Bessemer grade, with percentages around 0.015 to 0.025 or so. Sulphur is also low, thanks to the thorough weathering, except locally where there is much barite. This mineral is found in some quantity at Ouenza and the Sidi Safi group at Beni Saf, mostly as bunches and lenses of large crystal plates. It is also noted at many other mines, but in small quantities only. Some fluorite is associated with the barite at Ouenza. Copper as chalcocite and malachite is encountered in places in several mines, generally in small amounts. Compounds of lead, zinc, and arsenic seem to have an equally, or even more, restricted distribution.

Quantitatively the most important impurity—except perhaps remnants of the replaced limestone—is quartz, which mostly varies from 1 or 2 up to 5 per cent., but exceptionally runs up to 10. It is frequently developed as hexagonal prisms (Fig. 2), in a striking manner recalling Lindgren's figure of the "incipient silicification of limestone" at Aspen, Colorado.[2] Seldom are

[2] "Metasomatic Processes in Fissure Veins," *Trans. Am. Inst. Min. Eng.*, 30. 1901, p. 578; also reproduced in "Mineral Deposits" by the same author.

these quartz prisms large enough to be readily discerned with the naked eye, but the writer once noted a hematite ore in which they were more than a centimeter long, and still larger ones were seen

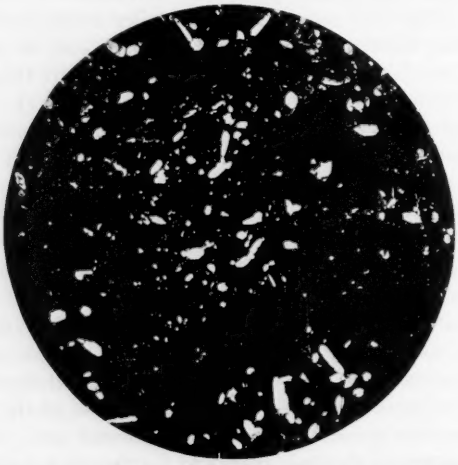

FIG. 2. Microphoto. of siliceous phase of Ouenza ore. Black is hematite, white quartz. × 15.

in the limonite phases of the Timezrit ore.[3] On the other hand, the length may go down to a few hundredths of a millimeter.

Algerian-Tunisian Group.—The group of deposits on the interior plateau around the Algerian-Tunisian boundary occurs in a country, the geological structure of which is particularly interesting, both in itself and in its connection with the ore deposits. The eastern part of this region, together with a large area in central Tunisia, was studied by Pervinquière, whose map (scale 1 : 200,000) and description were published in 1903. The Algerian side has not been mapped in the same manner, but some special studies are available (Blayac, Dussert, and others).

[3] Also in the Bilbao district, the writer saw such larger quartz prisms only in the limonite ore. They may perhaps belong to the supergene deposits, while the smaller prisms are certainly of hypogene origin.

The oldest formation exposed is the Triassic. It outcrops as patches generally some kilometers in diameter, sometimes with a distinctly anticlinal structure, and generally bounded by faults. This is the ordinary appearance of the Triassic in North Africa.

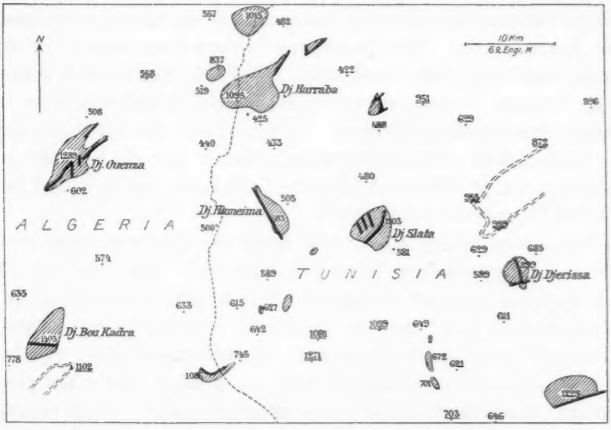

FIG. 3. Map of the Ouenza-Djerissa region, showing distribution of the Aptian. Scale 1 : 650,000.

It recalls the "bysmalitic" upward penetration of the salt domes, and in all probability depends upon the high gypsum content of the Triassic sediments. The Cretaceous is represented by the whole range from the Neocomian to the Senonian (including the Danian), and the sedimentation continued through the Lower and Middle Eocene. Unconformably overlying this series there are sediments of later Tertiary age, and Pleistocene alluvial deposits.

What interests us here is the Cretaceous-Eocene sedimentary series, which also occupies the larger part of the district. It is mainly built up of marls and limestones, and is deformed into rather gentle folds, only locally more accentuated. The general strike of the folding axes is N.E., but the influence of cross folds is conspicuous, resulting in the development of brachyanticlines

(domes) and the corresponding synclinal elements, all well shown on Pervinquière's map. The domes in particular are well marked. In their typical form, they consist of a quaquaversally dipping cone of Aptian strata (Lower Cretaceous), surrounded by the sequence of the later Cretaceous sediments, in the structure of which the domical form soon disappears, as one moves away from the Aptian center. Only in one case is there known a core of the next older stage, the Neocomian, below the Aptian in a dome. The Triassic is nowhere exposed within the domes, but often in their immediate neighborhood. In most cases, the domes are cut by steep faults. Sometimes these separate one dome from an adjacent one, in other cases a part of one dome has remained behind in the upward movement.

The Aptian mostly begins with sandy marls, but its upper portion is a rather massive, heavy limestone bed. The character of this rock, the shape of the domes, which have a circular or somewhat elliptical base, and the faults, all combine to make these structural elements conspicuous in the landscape. They rise as conical or somewhat elongated hills, steep-sided, and often presenting vertical fault scarps on one or several sides. Their height above the surrounding plain may be up to 700 meters. The other Cretaceous rocks are rather soft and as a rule do not give rise to any marked heights, only a series of banded limestones in the Senonian forms chains of rounded hillocks. A little higher up in the succession, a massive limestone of the lower Eocene, overlying the phosphate-bearing marls of the same formation, forms bold escarpments around the synclinal parts of the region.

It is always the Aptian limestone that carries the iron ores. The map compiled in Fig. 3 shows the distribution of the domes in the iron-bearing region. Six of the dome mountains are known to carry iron ore: Djebels (Mounts) Djerissa, Slata, and Hameima in Tunisia, Dj. Harraba on the frontier, Dj. Ouenza and Dj. Bou Kadra in Algeria. The geology shown in Fig. 3 is taken from the authors mentioned above, and the heights from the topographical map of Tunisia. The areas occupied by the Aptian are shown in hachures, and the faults that come into contact with

them in heavy lines. The height figures, in meters, are chosen to illustrate the differences between the Aptian mountains and the surrounding country. Underlined figures mark summits consisting of rocks younger than the Aptian. Some conspicuous crests of such rocks are indicated with double rows of broken lines.

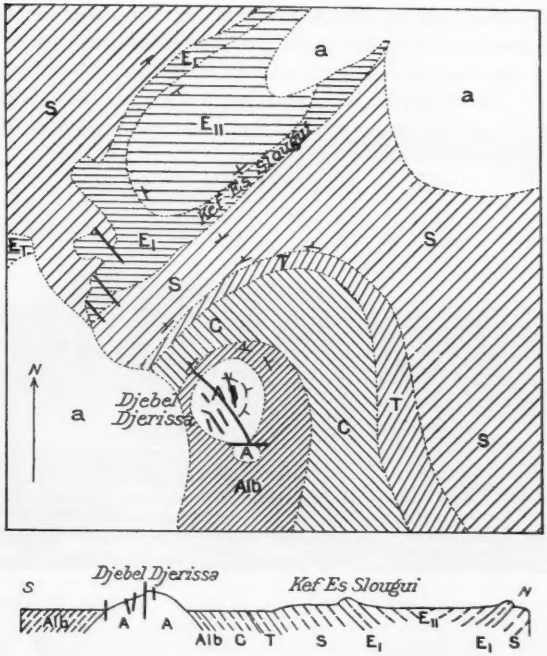

FIG. 4. Geological map of the surroundings of Djebel Djerissa (mainly from Pervinquière). Scale 1:250,000. Cretaceous: *A*, Aptian; *Alb*, Albian; *C*, Cenomanian; *T*, Turonian; *S*, Senonian (incl. Danian); Eocene: E_I, Lower, E_{II}, Middle Eocene; *a*, alluvial deposits.

Fig. 4 shows more in detail the geological situation of Djebel Djerissa. The Aptian dome is cut in two by a master fault, and

the western half is cut up by many smaller ones. These seem to go in various directions and not, as indicated with a necessary generalization on Pervinquière's map, all parallel to the main fault. Also the eastern half shows some faulting (see below). Another smaller dome, or rather half-dome, the Djerissa Srira, lies immediately to the south, separated from the other by a fault. Going north from the dome of Djerissa, one crosses a plain underlain in turn by Albian, Cenomanian, Turonian, and Senonian strata, mostly marls with thin limestone beds, but finally rising into the hills of the Senonian limestone. Above are the Lower Eocene marls, with phosphates (in this place without economic value), surmounted by the limestone escarpment of the Kef es Slougui.

FIG. 5. Djebel Djerissa from Kef es Slougui, showing the circular dome of Aptian strata rising above the flat country of later Cretaceous sediments, with hillocks of Senonian limestone in the foreground. Open cut to the left in the summit, mining town at the foot of the mountain.

Fig. 5 illustrates the topographical rôle of the Aptian dome.

The ore, then, occurs in the massive limestone bed of the dome. The longer axis of the outcrop runs in a north-southerly direction across the summit of the mountain. To the north, the ore dips

down below the upper Aptian strata, and its end is not yet reached by mining, while to the south it ends somewhat abruptly, terminating with a narrow zone of ore veins in the limestone (see Fig. 6). In a west-east section, the ore body shows an uneven but very distinct boundary against the limestone in the east, but more uneven contours on the western side, where beds of marl begin to alternate with the limestone, to which the replacement is always restricted. The contact with the marl that underlies the ore body is always quite sharp. Near the ore, the otherwise dis-

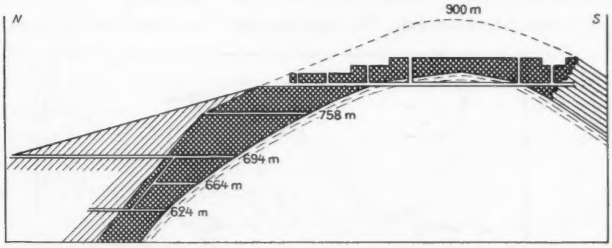

FIG. 6. Length section of the Djerissa deposit (after Berthon).

tinct stratification of the limestone has disappeared, apparently as an effect of metamorphism.

The ore body is cut by a later fault that makes an acute angle with its direction of strike, and dips to the west. It is a typical "hinge fault," with a displacement that increases downward. Some chalcocite and malachite are noted along it.

The western half of the Djerissa dome, broken by innumerable faults, contains a number of quite small ore bodies, none of which reaches a workable size. In some cases, the ore seems to have developed along a fault plane, in others, the faulting is distinctly later. There has been some futile prospecting for copper in the iron ore, caused by an occurrence similar to the one just mentioned above. In the Djerissa Srira, oxidized zinc ore has been found.

Also in the Djebel Slata, iron ore is being mined, but still greater importance attaches to a metasomatic lead deposit (Sidi

Amor ben Salem) in the same mountain. The iron ore has a much more irregular mode of occurrence than that of Djerissa, being mainly in the form of replacement veins. The structure of the Slata dome has been the subject of a study by Professor Fourmarier, to which reference will be made later. The low dome of Dj. Hameima likewise carries iron ore, partly as bodies conforming to the bedding of the limestone and partly as cross-cutting replacement veins. In quality it is not comparable to the others, as it contains much phosphorus and some arsenic. The ore bodies of Dj. Harraba are reported to be small.

On the Algerian side, Dj. Ouenza and Dj. Bou Kadra are ore-

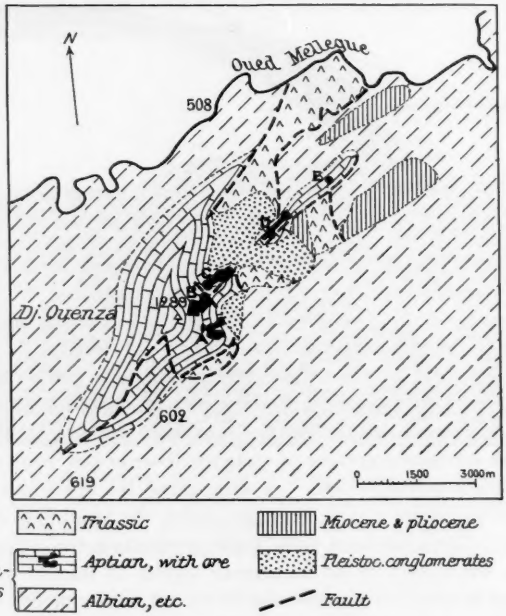

FIG. 7. Geological map of Djebel Ouenza (after Blayac and Dussert), scale 1:150,000. *A*, Koudiat Zerga; *B*, Chaggoura; *C*, Ste. Barbe; *D*, Hallatif; *E*, Douamis.

bearing. At the former, mining on a large scale has been going on for a number of years, while the Bou Kadra mine is still in a preparatory stage.

The Aptian dome of Dj. Ouenza, the summit of which attains a height of 700 meters above the surrounding plain, has a somewhat complicated anticlinal structure (Fig. 7). There is one main anticline, forming a ridge from the southwestern to the northeastern end of the mountain, and carrying the highest summit, and one that branches off just below this top and has a slightly more eastern direction. Several faults cut up the anticlines. Triassic sediments occur along a part of the eastern base of the Aptian limestone mountain, and also between the two anticlinal branches N.E. of the summit. They are bounded by fault or overthrust planes.

There are five different outcropping ore bodies. Of these, Ste. Barbe (previously also known as Koudiat Sauda) and Hallatif are opened up, and therefore are the best known portions. Together with the northeasternmost outcrop, Douamis, these form one continuous ore body, conforming to the anticlinal position of the limestone—a saddle reef, so to say, with a greatly undulating crest line. Sometimes the upper surface of the ore body has been exposed by erosion, as at Hallatif and Douamis, and even a portion of one flank removed, as at Ste. Barbe Between Hallatif and Douamis, where the pitch has carried the crest of the ore body to lower depths, a cover of limestone still remains, but the course can easily be traced from the old Roman workings—shafts of a man-hole's size that were put down in search of copper—the dumps of which show the presence of the iron ore body in a little depth. In the hollow between Hallatif and Ste. Barbe, again, the ore body once had been exposed but is now covered by a bed of Pleistocene conglomerates (Fig. 8).

The boundaries of the ore body against the limestone are rather distinct, although there may appear a narrow zone of veins. When, as sometimes happens, the ore ends against a layer of marl interstratified in the limestone, the contact is quite sharp. The ore contains some inclusions of limestone, rather coarsely crystal-

line and, at least in a specimen taken by the writer, somewhat dolomitic.

A fault runs nearly parallel to the strike of the Hallatif ore. along the southeastern side of the ore-bearing ridge. The fault

FIG. 8. Djebel Ouenza (summit concealed by a cloud) from Hallatif (N.E.). Open cut benches of Hallatif in the right foreground. The dark hill below the summit is Ste. Barbe.

plane is vertical, and shows a vertical striation. Triassic sediments on the southeastern side have been moved upwards to be on a level with the ore body. It may perhaps be the same fault that is noted further to the S.W., on the outer slope of the Ste. Barbe hill.

Ste. Barbe and Chaggoura are separated from each other by a fault, or a zone of faults. Chaggoura is not sufficiently exposed to permit a structural interpretation, but it seems most probable that it is a continuation of Ste. Barbe. Koudiat Zerga was not visited by the writer. Its structural position seems to be unknown, chiefly because of the abundant covering of conglomerate (consolidated talus). The idea has been advanced that the ore

bodies of Chaggoura and Koudiat Zerga replace another stratum in the limestone than those of Ste. Barbe, Hallatif, and Douamis. No observations proving this view are known to the writer.

The young conglomerates that are conspicuous at Ouenza belong to a characteristic formation that is represented over a large portion of North Africa and other Mediterranean countries. This formation is a hard, grayish-white limestone that covers the outcrops of solid rock, or cements the talus heaps to a conglomerate very much like concrete. In thick talus deposits, only the upper portions are hardened in this way. It is clear that the limestone has been formed by the evaporation of waters containing lime. While deposits of this nature form nowadays in desert climates, or particularly in semi-arid regions, they do not seem to develop under present conditions in the countries bordering the western Mediterranean. Pomel (quoted by Pervinquière) has expressed the opinion that most of these surficial limestones in the region in question date from a period of greater aridity in the early Pleistocene. This view is upheld by the results of later studies.

On the mountains that carry iron ore, the surficial limestone has other unwelcome effects than merely to veil the bed-rock surface, for by cementing solidly the upper parts of the talus deposits it has made it impossible to recover economically the quantities of rubble ore that are included in these deposits.

At the Djebel Bou Kadra, according to Dussert's description, most of the ore forms one heavy bank, replacing a certain level in the steeply dipping limestone.

The region now treated presents an unusual combination of problems in stratigraphy, structure, and ore deposition. It is evident that the metasomatic deposition of the ores was connected with the structural deformation of the strata. Faulting within the domes, obviously connected with the domical uplift, is known in several cases to have been later than the deposition of the ore. On the other hand may be cited the observations at Djerissa, where iron mineralization seems to follow one of the smaller faults, and where the fault cutting the ore body is accompanied by

a sulphidic impregnation. These facts indicate that probably all the mineralization took place during the final upthrust and accompanying faulting.

Among the Lower Cretaceous sediments, only the limestone of the Aptian reaches such a thickness that it can harbor iron ore deposits of economic importance. But it is worth noticing that no such deposition at all seems to have been recorded from the thinner beds of limestone of the later stages of the Lower Cretaceous. In the Upper Cretaceous, the Senonian limestone would seem to offer possibilities for a large-scale mineralization. The same holds true of the Lower Eocene limestone. But nowhere are ore deposits found in these rocks.

The mineralization is thus restricted to the marked domes, which offer a combination of favorable structural conditions—interference of folding directions that focussed the arising solutions to certain points, and fissuring that aided their upward movement—and also a rock adapted for replacement.

The obvious dependence on the structure makes it impossible to judge, to what extent the petrographical character of the Aptian limestone has determined the localization of the ore bodies. Nowhere are the other limestones of comparable dimensions, those of Senonian and Eocene age, found in structural positions similar to those of the Aptian, and, on the other hand, nowhere in the district in question is the Aptian exposed under other conditions.[4] It is even a matter of discussion whether the heavy limestone of the Aptian occurs at all outside the domes. This lithological phase of the Aptian in the Mediterranean region is often spoken of as a reef limestone, although its interpretation as a reef deposit is open to some doubt.[5] From the district now concerned, such

[4] In the Djebel Mesloula, 30 kilometers S.W. of Dj. Ouenza, the Aptian outcrops in the form of an elliptical syncline. This structure carries an important deposit of lead ore, but no iron. To judge from Blayac's map, one must reckon with the possibility that this syncline is the remaining part of a complicated dome of Aptian rocks, resting upon the Triassic.

[5] Compare Douvillé: "Ce faciès est généralement connu sous le nom de faciès récifal bien qu'on ne voie pas très nettement ses points de rapport avec les formations qui se dépose actuellement dans le voisinage des récifs coralliens." La Péninsule Ibérique: Espagne. Handb. d. reg. Geologie, Vol. III.: 3, p. 67. Heidelberg, 1911.

facts may be adduced as the change from a pure limestone series to one with intercalations of marl, as observed at Djerissa. Fourmarier, in his study of the Slata dome, found reasons to regard the massive limestone as an entirely local phase of the Aptian sediments around that mountain. He gives a very reasonable interpretation of the structure he has revealed, as resulting from an anticlinal folding of rocks of very different plasticity, and expresses the opinion that the Djebel Hameima also is formed by such an entirely local limestone body.

Yet one would hesitate to accept Fournarier's interpretation of Slata as a general explanation of the Aptian domes. The Slata lacks the regular quaquaversal dip of many other domes. It is difficult to see how the Aptian, just in its quality of an unyielding element, could—even with some fracturing—be folded into such structures. There is also much to be said for Pervinquière's explanation, according to which the domes are regarded as normal results of two folding movements, crossing each other at approximately right angles. The evidence for this view includes the existence of corresponding synclines with Eocene sediments, less accentuated, perhaps, but in principle comparable to the dome areas.

Perhaps the true explanation must be sought in a combination of those already presented. It may be that the presence of the more rigid portions in the column of strata helped to localize the points of intersection in the double folding, or that the true domes arose only where such points happened to coincide with the localization of the "reef" limestone. The rôle of the Triassic also presents a problem. Nowhere is a core of Triassic rocks exposed in the center of a dome, but they may be upfaulted along its sides, as seen at Dj. Ouenza.[6]

The solution of these structural problems apparently calls for more detail work, the results of which certainly would prove of more than local interest.

Among the iron ore deposits connected with the Liassic limestone, the writer visited Timezrit, Zaccar, and the Beni Saf dis-

[6] Compare also above, footnote relating to the Djebel Mesloula.

trict. Timezrit, a comparatively small mine, belongs to a rather numerous group of ore deposits in the country known as the "Kabylie des Babors." The Liassic limestone occurs as scattered patches, apparently the remnants of undulating synclinal folds. As everywhere in Algeria, it forms bold mountains. The Timezrit deposit consists of a discontinuous chain of ore bodies, more or less lenticular in horizontal sections, that follow the steep dip of the limestone. The outcrop was insignificant, but the dimensions increase greatly in depth. There are two different types of limestone, one grayish white, dense, and rather hard, the other yellowish, more coarse-grained, and softer. The former appears to be the normal one. In the quarries where limestone is taken for stope filling, the yellow variety may be seen, near its contact with the white form, to enclose large blocks of the latter, several meters in diameter, and also to contain small bodies of iron ore. It is said that generally the ore bodies of Timezrit lie between white and yellow limestone. In all probability, the latter is an altered form, the alteration having been connected with the deposition of the ore. It contains only a little iron, but a typical specimen collected by the writer was found to be strongly dolomitic.

The Liassic limestone of the Zaccar mountains occurs under other conditions; it forms a somewhat complicated anticline, bounded against the surrounding, mainly Cretaceous, rocks by faults and thrust planes. There are a number of different iron ore bodies in the limestone. The largest continuous body so far opened up has a strike length of 1,200 to 1,400 meters, and a varying thickness, probably averaging somewhat above 10 meters. The limestone shows a well-developed fine stratification of alternating bluish and white bands, often only a few millimeters thick, and also very distinct bedding joints that divide it into banks, generally between 5 and 50 centimeters in thickness. Thin seams of crystalline calcite often accentuate the bedding.

The limestone has a rather steep dip, although with many subordinate "rolls," the axes of which are practically horizontal. The ore body appears as an interstratified bed, partaking in the

changes in the dip of the limestone. Its boundaries are fairly distinct, not only when, as sometimes happens, a thin seam of slate or marl separates it from the pure limestone, but also against the latter. When following the ore body for some distance, how-

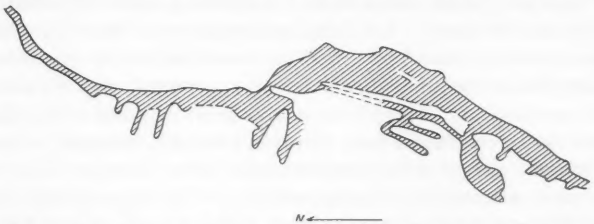

FIG. 9. Map of a part of the Zaccar ore body, showing influence of bedding and of cross fissures on the course of replacement. Scale 1:2,000. From a map given by the mining company.

ever, one is sure to find clear evidence of its metasomatic nature. There are some projections that branch off at an acute angle from the main ore body, and inclusions of limestone are rather frequently noted in the ore. In the southwestern part of the mine, the interstratified appearance of the ore body, which has been quite striking for a long distance, suddenly gives room for entirely different conditions; there is still an ore body along the bedding, but there project from it, often at right angles, equally thick branches, which sometimes in their turn, at some distance from the main ore "stratum," may send out branches along the bedding planes (Fig. 9). It is evident that the "gridiron" shapes arising in this way are due to the fact that, in this portion, cross-cutting fissures have offered the mineralizing solutions quite as good opportunities as the bedding planes.

The typical Zaccar ore is a mixture of hematite with limonite. It often displays a pronouncedly banded structure, with bands of solid ore, mostly 1 to 3 centimeters thick, separated from each other by narrower, drusy openings, coated and partly bridged by crystals of siderite (transformed into hematite) and "glaskopf" growths of limonite. The banding may also appear on

an even finer scale. It conforms to the outer shape of the ore body, and there can be little doubt that this banded ore forms a "metasomatic cast" of the lamination in the limestone.

The district of Beni Saf has long been famous as a producer of iron ore, which comes from a number of mines, all situated quite near the coast. The complicated geology of this region has been carefully studied by Gentil, but new features are now being unravelled in the mines that were never suspected when his work was carried out. Apart from smaller areas of other rocks, that need not be considered here, there are two main structural units: a bedrock mass of schists and limestone, and a younger cover of Miocene sediments and young volcanics. The latter group, and the Miocene deposits in particular, forms a cover over a large portion of the district where the ore-bearing limestone is thought to occur, and prospecting for new ore bodies is thus a difficult task. In several cases, the discovery of outcrops in the bottom of narrow ravines that cut through the Miocene has led to the development of important mines.

The schists, or rather phyllites, are interpreted as Silurian, but no fossils have been identified, and the evidence is therefore not conclusive. The limestone can, with more certainty, be correlated with limestone outcrops farther west, that are of proven Liassic age. According to Gentil's interpretation of the structure, the various limestone patches are synclinal downfoldings in the schists, and are the remnants left after erosion destroyed large parts of the once continuous bed. The recent developments just alluded to have complicated this picture by showing the presence of overthrusts. Thus schists, and even ore-bearing limestone resting on schists, are found to overlie limestone with ore. This structure has been encountered in the Sidi Safi group of mines, but it may perhaps have a wider distribution.

The Liassic limestone of Beni Saf is either rather massive, with sparsely spaced bedding joints, or more thinly bedded. The prevalence of the former variety probably explains the rather irregular shape of the ore bodies. Where a thin bedding appears, its influence upon the course of the mineralization is evident. At

one mine (El Gueten at Sidi Safi) there occurs a banded variety of ore that recalls that of Zaccar.

Origin of the Deposits.—The data given in the above descriptions will suffice to show that the ores were originally siderite bodies formed by a replacement of the limestone under the influence of ascending iron-bearing solutions. The possibility of an origin by descending waters is excluded by several facts, as, for example, the presence, in many cases, of a cover of limestone above the ore.

In the group connected with the Aptian limestone it was evident that the mineralization had been dependent upon the folding of the Cretaceous strata. The age of this folding, and of the ore deposits, in that particular region is not quite clear. Even the Pliocene is intensely folded, but it seems possible that the structure of the Cretaceous (and the Lower Eocene) was determined by a pre-Miocene folding. This would place the iron ores in the same age as those of the Algerian coast region. As is well brought out in Dussert's excellent survey of the iron ores of Algeria, these were in general formed before the Middle Miocene, or even before the Oligocene, since pebbles of ore are found in the supposedly Oligocene sediments near Beni Saf, but some smaller deposits are believed to be of Miocene age.

Some examples already mentioned illustrate the fact that a sulphidic mineralization, with copper, lead, zinc, and arsenic, has often followed shortly after the deposition of the iron ores. The larger sulphidic deposits of the region, however, chiefly lead and zinc, are never immediately connected with the iron ores, although evidently related to them.

The mineralization may be attributed to the influence of igneous centers at depth, not yet uncovered by erosion. But it must be admitted that the relation between igneous rocks and ore deposition has not been a very close one. Only one deposit of any importance, Sebabna (west of Rar el Maden), lies in the limestone along its contact with a decomposed igneous rock, regarded as a biotite-andesite. According to Dussert, there are no signs of any contact action from the side of the latter, therefore

the ore must have been introduced after the intrusion. A little west of the town of Miliana, on the southern slope of the Zaccars, there is an outcrop of a white rhyolite, the contact of which is in part followed by a narrow zone of iron ore (hematite and limonite). The writer had the impression of the contact relations that here was an example of later ore deposition in the Cretaceous shale along the boundary of the intrusive. We shall have cause to return to these questions later.

The Algerian and Tunisian ores are particularly favorable for a study of the relation between mineralization by replacement, and the stratigraphy and structure of the replaced rock. This is due to the fact that oxidation has mainly resulted in the forming of pseudomorphs after the original siderite, there having been no renewed replacement of limestone by iron that was set in movement by the oxidation process, at least not on an important scale. This fact allows us to see clearly the character of the hypogene mineralization in its relations to the country rock. As may be noted, the North African mines give good examples, both of a high degree of irregularity, and of an even more striking regularity in other cases. It is a conspicuous feature that there is so little mixture of ore and limestone. Where replacement has gone forward through the limestone, it has usually been complete, even if, accidentally, lumps of rock may have escaped and become enclosed as such in the ore. The way in which the replacement conforms to the bedding is quite remarkable in many cases. The influence in this respect of bedding joints and even quite thin intercalations of marl is obvious, but must not obscure the probability that also within a seemingly homogeneous column of limestone some beds are better adapted for replacement than others, just as, for instance, the Aptian seems to have been, also apart from its structural position, better suited than the Senonian and Eocene limestones.

The indications that some dolomitization has accompanied the iron mineralization are of interest. In the case of small quantities, it may represent the magnesia set free by the replacement of a somewhat dolomitic limestone, but at Timezrit there has been

a large-scale contribution of magnesia from the same source as the iron.

Comparison with the Bilbao District.[7]—There is no important difference in geological character between the iron ores just described and those of the Bilbao district in Spain. The latter occur in a limestone of Lower Cretaceous age (Urgo-Aptian), folded in early Tertiary time; the development of metasomatic siderite bodies started from the faults that were developed during the folding, and which are also followed by some intrusions; later, oxidation changed the siderite to hematite and limonite.

The only important differences, as far as the hypogene mineralization is concerned, lie in the more irregular character of the replacement at Bilbao, and in the fact that the ores were deposited at a somewhat later stage of the folding and faulting epoch, with the result that pre-mineral faults are more numerous, while in the African deposits post-mineral faulting is the rule. In the supergene process at Bilbao, much iron was set in movement, resulting in the development of limonite crusts ("rubio") and in supergene replacement of limestone. As just noted, this process was of little influence in the African ores.

It may be recalled that the same general type of iron ore is met with in various zones of Tertiary folding around the Mediterranean: also in certain parts of southern Spain, in the Sierra Menera (East Central Spain), and in the Alps of Austria (Eisenerz, Hüttenberg) is it encountered, in limestones of Mesozoic or Paleozoic age.

THE DISTRICT OF BENI BU IFRUR (SPANISH MOROCCO).

Through the studies of the Instituto Geológico de Espana, the geology of the iron-bearing country in eastern Rif, south of Melilla, is now fairly well known, and a visit was included in the program of the Geological Congress in 1926. The writer was not able to use this opportunity, but paid a brief visit to the Uixan mines somewhat earlier. Thanks to the courtesy of the Cia

[7] This comparison is based mainly upon impressions from the Bilbao excursions of the International Geological Congress, meeting in Spain in 1926.

Española de las Minas del Rif he could use the few hours available to the best advantage. Yet he would hesitate to consider this deposit here, even in the form of a summary of the Spanish reports, were it not for the fact that certain features invite a comparison with the deposits above described.

The studies of the Spanish geologists have demonstrated that the Rif is not, as generally shown on structural maps of the western Mediterranean region, a chain structurally different from the coast range of western Algeria, instead, it seems to be of the same age and forms a direct continuation.

The ore deposits occur in the mountains of the Beni Bu Ifrur tribe, about 20 kilometers S. of Melilla. The pre-Miocene rocks are schists, limestone, and dioritic intrusions. In the absence of fossils in many parts, the age of the sedimentary rocks has been difficult to determine, and opinion has changed as the geological knowledge of the region has increased. The phyllitic schists were regarded as Paleozoic in the first report (1912), and the limestone as possibly Triassic. Later (1917), the age of the former was reported as presumably Silurian, while the limestone was regarded as Liassic (in the center of the mountain) and Jurassic. In the most recent description, the congress guide of 1926, the schists are referred to the Jurassic, and also the limestone, except a patch in the southern part of the mountain group, which is classed as Liassic. From the necessarily brief review in the guide book it is not quite clear, to what extent this identification is based on the evidence of fossils.

The age problem has a wider interest, for the phyllitic schists and the limestone show great analogies to the presumably Silurian schists and the Liassic limestone in the coast region of western Algeria, as at Beni Saf.

The sedimentary rocks are intruded by a stock of diorite, in part quartz-bearing. Large dikes with a decidedly porphyritic texture branch out from the central intrusion.

The iron ores of the Uixan mountain and neighborhood (Monte Axaara) occur in the limestone, preferably at the contact with the schists, or along dioritic dikes. Some of these dikes,

however, appear to be later than the ores. Large inclusions of limestone illustrate the metasomatic character of the mineralization. The ore, as now exposed in the outcrops and the open cuts, is a mixture of magnetite and hematite. Specimens studied by the writer showed very plainly under the microscope the secondary (martitic) nature of the hematite. It is probable that by far the larger proportion of the hematite is of this origin, a product of the oxidation of the magnetite. There is also some specular hematite, evidently of primary origin, but this is quantitatively subordinated.

The least weathered ore is high in pyrite, but this mineral is leached from the more weathered parts, leaving only pores and cavities lined with a limonite crust, or filled with loose, earthy limonite. Other impurities are few and little conspicuous. Quartz is noted, in the form of rather short and thick prisms. Quite locally, the writer observed some barite.

The ore bodies form bold outcrops, from which aprons of talus ore spread out down the mountain slopes. These fragmental deposits are not consolidated, and form a considerable portion of the large ore reserves of the district. The quality of the ore is high, as its iron content is 60 to 65 per cent., and phosphorus low, although the high sulphur in the least weathered portions calls for roasting of this grade.

The origin of the Uixan and Axaara deposits has been the subject of much discussion. Rubio in 1912 postulates a magmatic origin for certain deposits and a contact-pneumatolytic origin for others. Dieckmann, who had mainly studied some of the eastern deposits in the group, interpreted them as magmatic. The greater extension of the mining operations in recent years has brought out much more clearly the geological relations. For the main deposits of Uixan, at least, the more recent reports indicate that the origin of the ores is referred to the contact action of the dioritic instrusions on the limestone. The present writer also has had this impression. But there are some features by which these deposits differ from those that are regarded as typical contact deposits. Most striking is the low silica. Contracts are

said (De Kalb, 1925) to be made upon a basis of maximum 8 per cent. silica, and any inspection of the workings will show that this low percentage can be kept without difficulty. In accordance with the low silica, there is an almost total absence of silicate gangue (skarn). The writer noted in one place a somewhat weathered greenish rock that looked as if it belonged to the schists, and that contained bands rich in magnetite. A microscopic examination shows that the green rock is mainly made up of pyroxene. This must be either a partial replacement, by iron and silica, of a limestone band, or else an introduction of iron alone into a marl layer. This observation suggests that skarn rocks may perhaps occur in some amount, and have escaped attention because they are so similar to the schists, but in any case their quantity must be quite moderate.

The substances introduced by the mineralization, then, were iron, and smaller amounts of sulphur and silica. This is just the combination that is characteristic of all the carbonate ores treated above, with very nearly the same proportions. The nearest representatives of the latter type, in fact, are quite close, for the recent descriptions by Del Valle (1926) of the iron ores of the "eastern group" in the Beni Bu Ifrur district, situated 6 kilometers E. of Uixan, make it plain that these deposits of porous hematite with much manganese are, as also interpreted by Del Valle, the oxidation products of originally carbonatic ores. They occur in a rather close connection with lead deposits that have a gangue consisting mainly of barite. Del Valle regards the district as an example of zonal deposition around the intrusive dioritic body, the magnetite-hematite ores being most closely related to this mother rock, the originally carbonatic ores next, and the lead ores most distant. This view is certainly upheld by the comparison here made with the Tunisian and Algerian deposits. It is worthy of note that, among the latter, those that carry high percentages of manganese are Rar el Maden and Sebabna, which lie farthest west and thus nearest to the Beni Bu Ifrur district. The low manganese of the magnetite ore—a few tenths of a per cent.—illustrates the common rule that contact deposits of iron are much

lower in manganese than the replacement bodies formed at a lower temperature.

The barite noted in the Uixan ore may also indicate a relationship with the siderite ores. It does not belong to the main mineralization period, as it occurs, not with the magnetite, but with limonite that can, from microscopic textures, be shown to have arisen from a carbonate. Probably there are here products of the very latest phase of the hypogene mineralization.

There seems, in short, to exist good reason for believing that the magnetite deposits of the Beni Bu Ifrur district are members of the same well-marked metallogenetic province as the originally sideritic ores of North Africa, only with that fundamental difference that the former were deposited in a much closer connection with their igneous mother rock. Thus also the view is strengthened that links the sideritic mineralization directly with igneous activity in greater depths.

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DIATOMS IN WESTERN OREGON SHALES.

HUBERT G. SCHENCK.

A CURRENT opinion among various geologists seems to be that there are few if any remains of diatoms in the Tertiary shales of western Oregon, or that any formation comparable to the diatomaceous shales of the Monterey Miocene of California is lacking in the western Oregon stratigraphic column. However, recent studies show that more investigation is needed before such opinions can be accepted, because diatoms are not exceptional in the Oregon shales.

Coscinodiscus fragments are fairly common in a gray sandy shale that outcrops on the divide between Amity and Hopewell, southern Yamhill county. The chief mineral grains visible under the microscope are quartz and feldspar. Some tuffaceous material is present, and perfect glass shards are not uncommon. The groundmass is finely divided detrital material, probably kaolin (see Fig. 1). An idea of relative percentages of minerals

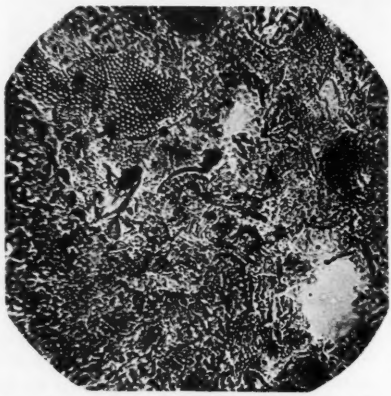

FIG. 1. Photomicrograph of tuffaceous shale containing fragments of marine diatoms from divide between Amity and Hopewell, southern Yamhill County, Oregon. (× 310.)

in the dry rock may be gained by calculations based upon the chemical analysis; namely, quartz, 39.9 per cent.; kaolin, 20.6 per cent.; albite, 15.5 per cent.; anorthite, 8 per cent.; orthoclase, 6.18 per cent.; limonite, 4.65 per cent.; chlorite, 3.26 per cent.; calcite, 2 per cent. These computations were made by use of a mineral slide rule [1] in order to translate the chemical analysis into terms of a plausible assemblage of minerals.

A similar shale containing *Coscinodiscus* and *Arachinoidiscus* occurs in Columbia County at several localities, especially about one and one half miles south of the town of Clatskanie, on the road to Mist. The fossils are associated with grains of quartz, feldspar, kaolin, hornblende, chlorite, glauconite, and an admixture of tuffaceous material (Fig.2). This may be compared with

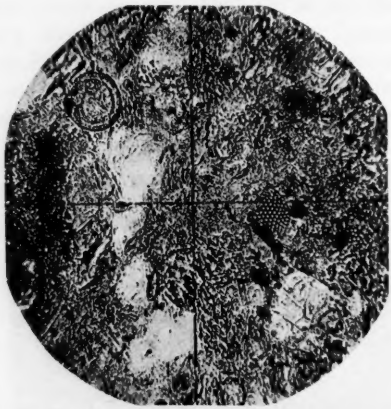

FIG. 2. Photomicrograph of tuffaceous shale containing fragments of marine diatoms from 1½ miles south of Clatskanie, Columbia County, Oregon. (× 200.)

the tuffaceous radiolarian shale described by Diller from the same region.[2] Calculations based upon the chemical analysis suggest

[1] Leith, C. K., and Mead, W. J., "Metamorphic Geology," pp. 299–302, 1915.

[2] Diller, Joseph Silas, "Geological reconnaissance in northwestern Oregon," U. S. Geol. Survey, *Seventeenth Annual Report*, part I., p. 470, 1896.

the occurrence of minerals in the following percentages: quartz, 29.8 per cent.; kaolin, 31.6 per cent.; albite, 16.9 per cent.; orthoclase, 5.9 per cent.; anorthite, 4.85 per cent.; limonite, 5.32 per cent.; chlorite, 3.97 per cent.; calcite, 0.63 per cent.

Chemical analyses of these and of two typical California diatomaceous shales are given in Table I. Comparisons show that the silica content of the Oregon samples is lower than that of the purer diatomaceous shales from other regions.[3]

TABLE I.

ANALYSES OF SAMPLES.

	Oregon Samples.		California Shales for comparison.	
	1.	2.	3.	4.
SiO_2	63.86	58.22	86.89	72.50
Al_2O_3	14.68	17.51	2.32	11.71
Fe_2O_3	3.68	5.44	1.28	2.35
MgO	1.06	1.20	Trace	0.83
CaO	2.53	1.16	0.43	0.32
Na_2O	1.70	1.80	2.32	Na_2O / K_2O } = 1.88
K_2O	0.97	0.87	1.26	
Combined water (+ 105° C.)	4.09	5.13		
Moisture (− 105° C.)	5.59	7.59	Ignition: 4.89	Ignition: 9.54
TiO_2	0.60	0.88		
MnO	Trace	Trace		
P_2O_5	0.20	Trace		
CO_2	0.82	0.25		
Cl	0.30	0.20		
	100.08	100.25	99.39	

1. Soft gray tuffaceous sandy shale; divide between Amity and Hopewell, southern Yamhill County, Oregon. Analyst, Smith-Emery, May 5, 1927.

2. Soft gray tuffaceous sandy shale; 1½ miles south of Clatskanie, Columbia County, Oregon. Analyst, Smith-Emery, May 5, 1927.

3. White shale, Monterey, Monterey County, Calif. Lawson A. C., and Posada, J. de la C., Univ. Calif. Publ. Bull. Dept. Geol., vol. 1, p. 25, 1893.

4. Soft white diatomaceous shale; Graciosa Ridge, 3 miles southeast of Orcutt, Santa Barbara county, Calif. W. T. Schaller, Analyst, 1907. See English, U. S. Geol. Surv. Bull. 768, p. 29, 1926.

[3] Roth, J., "Allgemeine und Chemische Geologie," 2d vol., p. 672, 1887; California State Mining Bureau, Bull. 38, p. 289, 1906; Arnold, R., and Anderson, R., U. S. Geol. Surv. Bull. 315, p. 445, 1907.

A shale that closely resembles megascopically some of the California Monterey shale occurs in the hills northwest of Smithfield, eastern Polk County. The resemblance is so great that a well-known economic geologist in California termed the Oregon sample "Monterey Shale." As in the other instances, the diatom fragments are associated with tuffaceous material. At another locality in the same county, one and one half miles south of Bethel, diatoms are present in a gray sandy shale.

The occurrence of *Coscinodiscus* in the Bassendorf Shale, Coos County, has already been reported.[4] Other dark-colored shales that contain these fossils outcrop in the vicinity of Waldport and Newport, Lincoln County, and at Astoria, Clatsop County.

The writer has been convinced by this study that when further microscopic investigations of the sedimentary rocks of Oregon are undertaken the conclusion will be reached that many of them have not received appropriate names.

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[4] Schenck, Hubert G., "Marine Oligocene of Oregon," *University of California Publ. Bull. Dept. Geol. Sci.*, vol. 16, no. 2, p. 454, March 19, 1927.

ORE DEPOSITS OF THE RIO TINTO (HUELVA) DISTRICT, SPAIN.

ALAN M. BATEMAN.

CONTENTS.

Introduction 570
Geologic Setting of Ore Deposits 570
Topography 570
Rock Formations and Structure 572
Resumé of Development of President Topography 576
Ore Deposits 576
General 576
The ores 577
Character and form of deposits 578
Dimensions of orebodies 578
Relation of dimensions to erosion 579
Relation of deposits to enclosing rocks 579
Distribution of ore shoots 580
Accompanying rock alteration 581
Physical conditions of formation 583
Mineralogy of Deposits 584
Occurrence of ore minerals 584
Massive sulphide 584
Disseminated sulphide 585
Ore minerals of the deposits 585
General 585
Primary minerals 586
Secondary sulphides 591
Oxidation and enrichment 592
The gossans 592
Secondary enrichment 596
Discussion of Origin 602
Previous ideas 602
The problem of origin 605
Objections to magmatic origin 605
Replacement origin 607
Summary 611

INTRODUCTION.

THE pyritic orebodies of the Huelva district are the oldest worked, and most important copper-sulphur deposits of the world, having been mined since the time of the Phoenicians. But their chief interest to the geologist lies in the puzzling question of their origin. Any additional information concerning such deposits may throw light not only on the problems connected with similar deposits elsewhere, but also on those concerned with the origin of ore deposits in general. The purpose of the present paper is to present such information regarding the Huelva ore deposits.

These deposits, perhaps better known among English-speaking geologists as the Rio Tinto deposits, were visited during 1926 by members of the International Geologic Congress, including myself; subsequent discussions during the Congress indicated great diversity of opinion regarding their origin.

During the visit I was impressed by certain similarities between the deposits of Huelva and many of the replacement copper deposits in North America. This, and other direct observations, suggested that they had been formed by metasomatic replacement. Through the courtesy of the mine officials, particularly those of the Rio Tinto, Tharsis and La Zarza mines, an opportunity was afforded to make a representative collection of specimens. These were chosen specifically to determine whether the deposits had originated by replacement or in some other manner. Subsequent laboratory study confirmed the working hypothesis formed in the field. This paper presents, as a basis for discussion, support and confirmation of a replacement origin for the Huelva deposits.

GEOLOGIC SETTING OF THE ORE DEPOSITS.

Topography.—The Rio Tinto and nearby Tharsis and La Zarza mines of the Huelva district lie in southwestern Spain in the Sierra de Arcena, a part of the Sierra Morena mountains, which form the southern margin of the interior tableland of Central Spain. (See Fig. 1.) The important Atlantic seaport of Huelva acts as a hub from which radiate spokelike lines of access to the important properties. For there are more than the three mines mentioned above; some thirty-three lie in a zone that ex-

tends eighty miles across the province of Huelva and into Portugal. We of the Congress saw only those around the three places mentioned above, some fourteen lodes in all.

FIG. 1. Outline map of Spain, showing location of Rio Tinto and Huelva.

From Huelva extend the rivers Odiel and Tinto, the former up into the country of Tharsis and La Zarza and the latter to Rio Tinto. They converge to form an estuary at Huelva, but in their upper reaches they are racing streams in steep-walled inner valleys.

The land rises gently northward from the sea to the headwaters of these streams, where the Sierra Morena mountains merge into the Meseta, reaching a maximum elevation of around 3,000 feet. These mountains are subdued; the slopes are gentle; prominent peaks or bold ridges are absent, and the elevations are accordant. The stream valleys, except for the lower shallow notches, are in general mature. The streams cross the strike of the rock formations, and where they intersect resistant rocks there are steep-notched gaps which alternate, where softer rocks intervene, with flattish areas. The tributaries are in trellis pattern parallel to the strike of the rocks, and follow the softer beds; prominent ridges of resistant rocks lie between them.

The lower slopes support a fertile soil mantle, and groves of olive, orange, and cork trees flourish. The upper slopes are devoid of timber, and are covered by a thin mantle of disintegrated rock and boulders. What soil there was has been washed away since the region was denuded of timber.

Rock Formations and Structure.—The Sierra Morena mountains, forming the southern margin of the Meseta Espanõla, or Spanish Plateau, are made up of folded Paloezoic formations and intrusives. These are separated by the great Guadalquivir fault from the flat-lying Tertiary beds of the Guadalquivir Valley to the south. Farther to the south are the younger folded ranges of the so-called Betic Cordilleras. The Guadalquivir fault passes through Huelva, and the ore deposits lie north of it in the older rocks of the Meseta. These rocks show the results of intense late Carboniferous—early Permian (Hercynian) folding. The original Paleozoic sediments were converted to schists and slates, and now dip at high angles.[1] The folds here trend almost east and west and terminate against the northeasterly trending Guadalquivir fault. Accompanying the folding were intrusions of granite and allied rocks. The ore deposits, not only the pyritic deposits of the Huelva district but also the mercury ores of the Almaden, and the lead-silver ores of the Linares-Carolina districts and others, are believed to have originated with these intrusions.

The rocks in the vicinity of the mines (see Fig. 2) consist of slates, argillaceous schists and phyllites, and acidic and basic intrusives. Hereza,[2] following Gonzalo y Tarin[3] and Mallada,[4] regards the sediments as of Silurian and Culm (Lower Carboniferous) age, and states that the Silurian and Culm can be separated on the basis of paleontological evidence and on lithologic grounds—the Silurian slates being reddish. Finlayson,[5]

[1] Much faulting accompanied the folding, and the Guadalquivir fault is considered by Hereza to be the last and greatest expression of those forces. See "Metalliferous Deposits of Linares and Huelva," by J. Hereza and A. de Alvarado, 14th Int. Geol. Cong. Guide Book, A–3, p. 10, Madrid, 1926.

[2] Guide Book A–3, 14th Int. Geol. Congress, pp. 84–86, Madrid, 1926.

[3] Spanish Geological Commission, 1886.

[4] Mem. Com. Map. Geol. Esp., Madrid, vol. I., 1886.

[5] "Pyritic Deposits of Huelva, Spain," ECON. GEOL., vol. 5, p. 362, 1910. Fin-

FIG.

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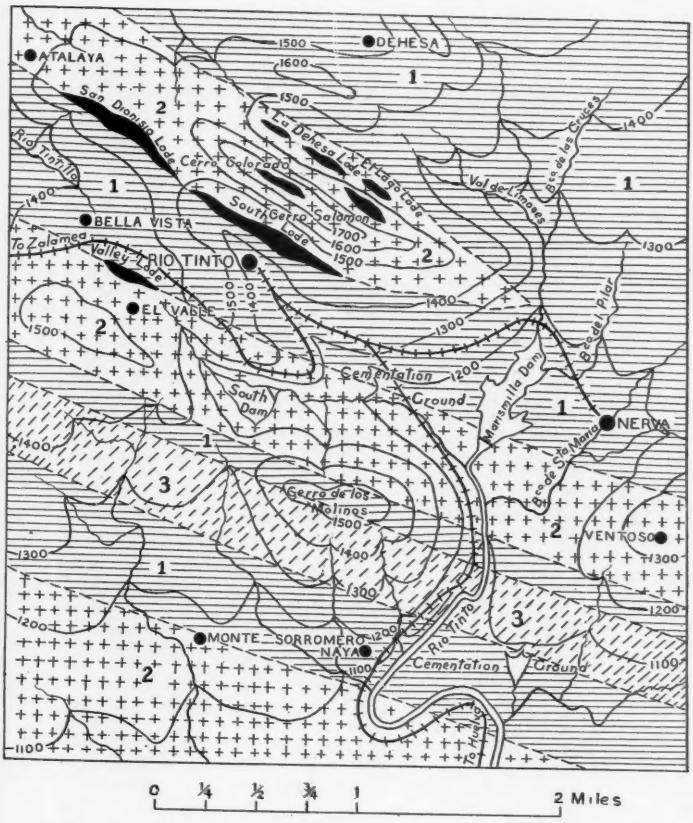

FIG. 2. Geological map of Rio Tinto. 1 = slate; 2 = porphyry; 3 = diabase; black = lodes. From Finlayson.

layson points out that he found *becheri*, a Culm fossil, in slates mapped as Silurian near Tharsis, and doubts that any lithologic separation can be made between Silurian and Culm. The authors of the Guide Book A–3 of the Fourteenth International Geologic Congress had not had access to Finlayson's paper and consequently were not aware of his conclusions.

however, thinks all the slates are of Culm age. The black slates (and the reddish facies also) have in places near the ore been altered to light colored rocks, consisting essentially of sericite, or sericite and kaolin. The igneous rocks around the mines are acid porphyries and diabases.[6] These are aligned as broad bands or elongated lenses parallel with the folding of the district. The porphyries were previously[7] considered to be intrusives, extrusives, or regional and contact metamorphic rocks. Finlayson[7] agrees with Vogt that they are intrusive dikes or sills. He differentiates quartz-porphyry or rhyolite porphyry, granophyric quartz-porphyry, and quartz-keratophyre, and points out that most of them are marginally sheared by later dynamic metamorphism and grade into highly cleaved facies that may be altered beyond recognition. He concludes they belong to the same stage of intrusion as the granites, but that they are older than the chief earth movements of Permo-Carboniferous time.

The most extensive study of the igneous rocks of the region has been made by H. F. Collins. His "tentative conclusions" from "preliminary work"[8] establish the existence of tuffs and lavas, and he thinks that Klockmann[9] was right in contending that some of the sheared porphyries are altered tuffs. However, Collins and Finlayson agree, except in minor details, that the porphyries are mainly intrusives. Hereza[10] also considers them to be intrusives of felsitic texture but apparently calls them "diabase porphyries." Edge and Demay[11] consider them to be quartz-porphyries of felsitic texture.

My few slides add but little information to the thorough studies

[6] According to Finlayson (*op. cit.*, p. 362–363) some granites and associated intrusives occur near by; these are chiefly muscovite or biotite granite, granodiorite, monzonite and tonalite, and intrude the slates and some older diorite. They are themselves intruded by felsite and diabase.

[7] *Ibid.*, pp. 363–367.

[8] "Igneous Rocks of the Province of Huelva and Genesis of the Pyritic Orebodies." *Tr. Inst. Min. and Met.*, vol. 31, pp. 61–81, 1921.

[9] Klockmann, F., "Spanisch-Portuguesische Kiesvorkommen," *Zeit. f. prakt. Geol.*, vol. 3, p. 86, 1895.

[10] Guide Book A–3, 14th Int. Geol. Cong. Madrid, p. 86, 1926.

[11] A. Broughton Edge and Andre Demay. Papers read in the technical sessions, Fourteenth Int. Geol. Cong., Madrid, May, 1926.

by Finlayson and Collins. Those examined are predominantly quartz-porphyries or rhyolite-porphyries. Quartz phenocrysts, often embayed, dominate; phenocrysts of orthoclase or rare albite were also seen. The groundmass is fine-grained or crypto-crystalline, and consists essentially of quartz and feldspar grains. Micropegmatitic intergrowths of quartz and feldspar are common. My specimens, since they represent the igneous rocks adjacent to and containing the ore, show profound sericitic and chloritic alteration. This alteration seems more prominent than is indicated by Finlayson's description, since his specimens were collected largely from the fresher rocks to determine their origin rather than to elucidate the ore processes by the character of their alteration. Collins' descriptions, however, indicate that considerable alteration has occurred.

Diabases and related rocks occur as sills and dikes in the vicinity of the orebodies [12] (see Fig. 2). They consist essentially of lath-shaped feldspars, chiefly oligoclase or andesine; augite, in part altered to secondary hornblende or chlorite; and of ilmenite, olivine, and sphene. Finlayson [13] says they are the youngest series of the district, that they cut the porphyries, and that they are unaffected by the dynamic processes that sheared the porphyries; hence they were intruded near the end of the folding. Collins is not certain that they are the latest intrusives of the district.

It is of interest to note that similar diabases occur farther north at the Almaden quicksilver deposits. They may represent intrusions of the same age and of the same igneous activity. At Almaden they are the only nearby igneous rocks and may be responsible for the presence of the quicksilver.

Faulting is prominent, and several dislocations of ore have been noted. The greatest dislocation at Rio Tinto [14] is a fault of northwest trend with a throw of 220 meters; it faults the San Dionisio and South orebodies, creating much drag ore between

[12] One prominent sill at Rio Tinto, one-third of a mile wide, lies just south of the main orebodies, and smaller dikes are numerous.

[13] *Op. cit.*, p. 369.

[14] Brought to my attention by Mr. Paul Cauldrey of Rio Tinto.

them. These two colossal ore masses are considered to have been originally the same continuous body with a total over-all length of around 3,000 meters.

Resumé of Development of Present Topography.—The land forms of today in the vicinity of the mines evidently have resulted from the dissection of a peneplain [15] whose level is marked by the uniform elevations of the present hilltops. It cut across the intrusives and the folded metamorphic rocks just described. The erosion that produced it also exposed the ore deposits. Cerro Colorado and Cerro Salomon rise as monadnocks above this peneplain level.

Later elevation caused rejuvenated stream erosion, giving rise to the present mature valleys beneath the peneplain level. The relief of the monadnocks was accentuated; the hills were rounded; the Rio Tinto became a superimposed stream and now crosses, almost at right angles, the strike of the rocks. It cut notches in the hard beds that lie in its course, and flaring gentle slopes in the softer rocks. The trellis drainage pattern of the tributaries was controlled by the east-west structure and erosional susceptibility of the rocks. They excavated their valleys along the softer formations, leaving ridges of resistant rocks. The tributaries are thus subsequent streams.

A small recent uplift [16] is shown by the notched stream bottoms and the narrowing stream gorges towards the Guadalquivir fault.

ORE DEPOSITS.

General.—The chief interest of the Huelva district is in the colossal pyritic deposits.[17] They are probably the most important

[15] My observations are insufficient to date the peneplain. The finding elsewhere of truncated Miocene beds suggests that it is post-Miocene in age. However, there was deep erosion to produce the surface upon which the continental Miocene beds of the Meseta were laid down, and this erosion probably reached a peneplain stage. If this was the case the truncation of Miocene beds was a part of the peneplain dissection.

[16] This was probably a renewed uplift along the Guadalquivir fault which must have existed in pre-miocene time since it separates continental miocene of the Meseta from marine miocene of the Guadalquivir Valley.

[17] It is thought that the Phoenicians mined the gossans of these deposits for

copper deposits of the world, and are the largest deposits of pyrite. Vogt[18] estimated that up to 1908 these properties had produced some 125 million tons of pyrite containing 1 to 3 per cent. of copper, which with the ore developed at that time meant that a group of the larger mines contained some 200 million tons of ore with a copper content of 4 to 5 million tons. From 1908 to 1925, Spain and Portugal have produced 825,000 metric tons of copper.[19] The production to date is probably in the neighborhood of 175 million tons of pyrite with 3 to 4 million tons of copper.[20] The mines still have many years of life ahead of them.

The orebodies and the enclosing rocks have been extensively described, but the ore itself, since its massive character conceals its inner features, has received relatively little attention. The advances in the use of the reflecting microscope now enable us to glean further records from a study of the opaque ores—records that remove some of the uncertainty regarding the origin of the deposits. It is advisable, however, before discussing the origin, to present a few pertinent features regarding the character of the ores and their occurrence and to round up widely scattered information in the literature.

The Ores.—The mines are worked, chiefly by means of colossal open cuts (see Fig. 3), for copper and sulphur, though silver and gold add to the value. A little lead and zinc are also won, and there are traces of arsenic, antimony, cobalt, nickel, selenium, tellurium and other metals. The ore as mined is classified as (1) direct smelting ore, containing 2½ to 3 per cent. copper, which goes directly to the smelter; (2) leaching ore, or heap ore, with 0.5 to 2 per cent. copper and 30 to 50 per cent. sulphur, which is sent to the great leaching heaps; (3) cupriferous sulphur ore,

silver and gold. Roman shafts, tunnels and open cuts (started in 43 B.C.) are still visible; huge Roman slag dumps supply ballast for the local railways. An archimedes screw and dewatering wheels have been found, and many Roman implements repose in an interesting museum at Rio Tinto.

[18] *Op. cit.*, p. 336; 199.

[19] *Mineral Industry*, 1908–1925.

[20] If the amount of ore removed by erosion equals that extracted and developed, there may have been approximately 500 million tons of pyrite and 10 million tons of copper originally concentrated in this region.

which contains up to 2 per cent. copper and from 50 to 55 per cent. sulphur;[21] (4) sulphur ore[22] of about 55 per cent. sulphur and a low copper content, around 0.3 per cent. The ores of La Zarza and Tharsis are lower in copper than those of Rio Tinto, and are sold chiefly as sulphur ore. Some of the smaller deposits and localized parts of larger masses may contain a higher proportion of copper and yield 5 to 10 per cent. copper ores.[23]

Character and Form of Deposits.—The ore deposits are elongated in an easterly-westerly direction parallel to the structure of the region. Though widely spread in a long, narrow zone, the important bodies occur in relatively localized groups within the zone, and are arranged *en echelon.* Thus at Rio Tinto there are (see Fig. 2) eight important lodes outcropping,[24] known respectively as San Dionisio, South, El Valle, Cerro Colorado, Cerro Salomon, La Dehesa, North, and El Lago. The individual orebodies generally dip steeply north and have the form of huge lenses. In detail, the main body of the lodes is solid sulphide with a fringe of disseminated sulphides on one or both sides. The solid sulphide, of course, is all ore, either of copper or sulphur, but the amount of disseminated sulphides included as ore is determined by its copper content and will obviously vary with the changing economics of copper mining.

Dimensions of Orebodies.—When one views these deposits for the first time he is impressed by their enormous size, particularly by the great masses of almost solid sulphide. At Rio Tinto the San Dionisio lode is 1,050 meters long, and the South lode is 1,700 meters long. The Eduardo deposit of broken drag ore lies between them; the ore in all three bodies is essentially continuous with a total length of 3,000 meters. The maximum width of San Dionisio is 250 meters and of the South lode, 160 meters. The La Zarza lode has a length of 1,300 meters and a width of

[21] The copper content of this class of ore is extracted during the winning of the sulphur.

[22] The sulphur ores are sent chiefly to England, Holland and Germany; a small amount is used near Huelva in making fertilizer.

[23] Finlayson, *op. cit.* Hereza, *op. cit.*

[24] Others, such as the Eduardo deposit, do not outcrop.

60 meters. Finlayson states [25] that the great majority of lodes vary between 300 and 700 meters in length, and a few are less than 200 meters; and in width between 50 and 150 meters, with some smaller ones between 15 and 30 meters. There seems to be a rough proportion between the maximum of length and width, the length being commonly 2.5 to 6 times greater than the width, although in a few cases it reaches a higher figure. The lodes of largest surface outcrop also appear to have the greatest depth. Thus the San Dionisio open cut has reached a depth of 437 meters, and drilling has shown the ore to extend at least 100 meters deeper. This is the deepest known deposit of the district.

Relation of Dimensions to Erosion.—A study of the physiography indicates that less erosion of the region would have resulted in some deposits being of greater depth than they now are, and that several present-day outcrops would not have been exposed at the surface.[26] Originally the lodes must have had a much greater vertical range than at present, perhaps up to 1,500 meters. Finlayson [27] thinks that 1,000 meters was probably the maximum vertical range, that few originally exceeded 500 meters in depth, and that most of them today are less than 300 meters deep. Even a brief visit to the region suggests that more ore has been removed by erosion than is now indicated by the exposed remnants of the original lodes. Descriptions in the literature suggest strongly that many of the shallower deposits are simply the roots of lodes the greater part of which has been denuded. Also the geology of the region suggests that in all probability there are still other hidden lodes whose tops have not yet been exposed by erosion. The region should prove a fertile field for subsurface prospecting by geophysical methods whenever economic conditions make it desirable to increase ore reserves.

Relation of Deposits to Enclosing Rocks.—As mentioned pre-

[25] *Op. cit.*, p. 405.

[26] Conversely, greater erosion would have removed entirely a few deposits whose roots only are now exposed, and revealed others at the surface that are known to have "blind" outcrops.

[27] *Op. cit.*, p. 405.

viously, the host rocks of the orebodies are slate, porphyry, and diabase. Finlayson points out [28] that of the 33 chief lodes of the whole district, 11 are at the junction of porphyry and slate, 2 are at the junction of slate and diabase, and 16 are enclosed wholly in slate. Collins, on the other hand, referring to the orebodies in slate, says [29] that they are mainly if not always associated with "horses" or lenses of slate that lie within broad igneous belts and tail out in depth, rather than in broad slate belts. He also says [30] that "even when both walls are slate there is almost invariably a dike of igneous rock running parallel to the orebody."

The association of ore with slate or diabase may not be so intimate as is implied by the surface relations. For example, of the eight important outcrops of orebodies at Rio Tinto, five lie wholly in porphyry, and three are at the contact of porphyry and slate. (See Fig. 2.) But of the latter, the San Dionisio and South lodes are on the north side, and the Valley lode is on the south side, of a band of slate that pinches in depth; [31] the orebodies continue down to unknown depths into the inclosing porphyry. This ore has then come from within or through the porphyry. Consequently, at Rio Tinto, there is a close association of ore with porphyry but only an incidental one with slate. Also, those bodies which on the surface lie in contact with slate do not grade appreciably into slate, whereas they do grade into porphyry. The slate is thus in general a bounding rock rather than an inclosing rock. A similar condition exists at the Tharsis mine, to the west.

The localization of many of the orebodies at porphyry-slate or porphyry-diabase contacts apparently was controlled by the lines of structural weakness there existing, rather than by any properties of the slate or diabase.

Distribution of Ore Shoots.—The writer had no opportunity in his brief visit to study the distribution of copper within the orebodies. Finlayson, however, notes [32] though with local excep-

[28] *Op. cit.*, p. 407.
[29] *Op. cit.*, p. 81.
[30] *Op. cit.*, p. 83.
[31] Verbal information given by Mr. Paul Cauldrey of Rio Tinto.
[32] *Op. cit.*, p. 412.

tions, a progressive decrease with depth of copper content in the primary ore. He also observed [33] shoots of 2 per cent. copper ore surrounded by lower grade material containing from ½ to 1 per cent. copper. He points out that the higher copper ore tends to be concentrated in the centers of the lodes. Similarly Collins [34] observed local concentrations of copper in certain parts of the lodes, and discusses this at length under the term "deep-seated primary enrichment." He shows that in the smaller orebodies, to which his study was largely confined, ore shoots are more prevalent than in the large deposits; he cites [35] one instance of a 13 per cent. copper ore within material carrying only 0.5 per cent. copper.[36] He thinks, however, that the localizations of copper have been caused by circulation of copper-rich solutions subsequent to the pyrite metallization [37]—a conclusion that will be discussed later.

Accompanying Rock Alteration.—One of the features that most attracted my attention when I saw the Huelva deposits was the intense sericitization of the mineralized porphyry and slate that border the great sulphide masses. It is more pronounced and widespread in porphyry than in slate. Within the massive ore itself, of course, nothing but sulphide is visible; it is the margins of the deposits that yield the information of greatest value, and in this respect the La Zarza deposit is instructive. The pyritized porphyry immediately north of the massive sulphide is almost completely sericitized to a grayish-white rock.[38] Farther north, an aureole of less sericitized porphyry envelops the pyritized porphyry and merges gradually outward into unsericitized rock. Also, the black and red slates have in places been changed to white rocks of talcy feel that consist almost wholly of sericite.

A less intense phase of rock alteration converted the porphyritic

[33] *Idem.*

[34] *Op. cit.*, p. 89.

[35] *Op. cit.*, p. 91.

[36] This unusual concentration he thinks is caused by localization of copper in an included slate "horse."

[37] Collins appears to disagree with Finlayson in calling these localizations of copper, ore shoots.

[38] Some of the light color is due to kaolinization.

rocks largely to chlorite, epidote, and quartz, with minor sericite. This is more characteristic of the outer margin of the zone of alteration, or of the sparsely pyritized porphyry.

The sericitization is thus intimately associated with the ore, and disappears as distance from the ore is gained. It is clearly related to the formation of the ore, and was just as much a part of the metallization process as was the ore itself.

Microscopic examination of thin sections shows that sericite has formed most abundantly where sulphides constitute a large proportion of the rock; where sulphides are few the sericite is less. All the rock-forming minerals have been replaced by sericite, the feldspar most and the quartz least. Residuals of quartz, partly penetrated by rods of sericite or embayed by a felted mass of sericite fibers, lie wholly included in sericite. A few residual specks of magnetite are also inclosed in sericite—evidently an original rock constituent that resisted alteration. Individual grains of pyrite are surrounded by halos of sericite. Some silification occurs in the most altered rock, nearest the ore, as on the north side of the La Zarza orebody. But the large amount of added silica mentioned by Collins [39] is, in my opinion, due to the numerous small veinlets of quartz that ramify through the altered rock rather than to a silicification of the rock as a whole. One specimen with much disseminated sulphide, from the hanging wall of the Dionisio orebody at Rio Tinto, contains no sericite, but is so completely altered to chlorite that its original character cannot be deciphered.

Finlayson noted abundant sericite as an alteration of feldspar or of slate, but ascribed it to the pressure that produced the cleavage in the porphyries, and the slaty cleavage in the slates.[40] Thus, according to his conclusion, it would follow that the sericite had been formed in the slate before the porphyry intrusions, or else that the cleavage in the slates was not developed until after the intrusion had taken place. Neither deduction is substantiated by field or microscopic study, for the porphyry is sericiticized even more than the slates, and the fringe of sericitized slate has no

[39] *Op. cit.*, pp. 157–158.
[40] *Op. cit.*, p. 370.

more slaty cleavage than the unsericitized slate [41] beyond. The sericitization (and likewise the ore) is later than both the porphyry consolidation and the shearing of the slates.

It is clear that Finlayson did not link the intense sericitic alteration with the metallization; in this respect my opinion differs from his.

Collins also refers repeatedly to the pronounced sericitic alteration. But he, like Finlayson, attributes a part of it at least to shearing,[42] though some of it, he recognizes, was formed by mineralizing solutions.[43]

A later and different kind of rock alteration; namely, kaolinization, has been superimposed upon the earlier one; sericitized or chloritized varieties have been partially altered to kaolin. Under the microscope kaolinite can be clearly seen to replace sericite or chlorite; to a less extent it also replaces unsericitized feldspar. This kaolinization of sericitic rocks, in Huelva as elsewhere, takes place by solutions that originate during oxidation, and is a usual alteration where ore deposits undergo oxidation and enrichment. In fact, the degree of kaolinization is, oftentimes, a criterion of the amount of oxidation and enrichment that has taken place. The sericitization is thus a result of primary metallization; the kaolinization, of oxidation and enrichment.

The bearing of the rock alteration on the problem of ore genesis will be referred to later.

Physical Conditions of Formation.—The Huelva primary ores consist mainly of sulphides, with minor arsenides, sulpharsenides, sulphantimonides and quartz. All these are mineral combinations customarily formed under conditions of intermediate temperature and pressure. High temperature minerals are absent; there are no metallic oxides, no tourmaline, garnet, topaz, or biotite, pyroxenes, or amphibole, as introduced minerals. The

[41] It is realized that some slates consist largely of sericite, *i.e.* sericite slates, but the distinction at Huelva is clear; those slates affected by mineralizing solutions are whitened, those unaffected are black (or red). The whitened phases are produced by development of sericite; they may be further bleached by acid water leaching, producing kaolin. (See next paragraph.)

[42] *Op. cit.*, p. 65; 78.

[43] *Op. cit.*, p. 152.

minerals and their occurrence indicate deposits formed at intermediate depths.[44] No definite figure of the depth of formation is supplied by the geology of the Huelva district, but from the preceding discussions it is evident that several thousands of feet of cover have been eroded from the tops of the orebodies.

MINERALOGY OF DEPOSITS.

Occurrence of Ore Minerals.

The deposits contain both massive and disseminated sulphides; the former makes up the main part of the deposits, and the latter is of less volume and of relatively low value (see Fig. 3).

FIG. 3. Looking east at end of pit at Tharsis. Los Silos in background. Light is pyrite with large dark inclusions of highly altered country rock. Slate at right; porphyry with disseminated sulphide at left. Photo by J. T. Singewald.

Massive Sulphide.—The massive sulphide is hard, compact, breaks with a conchoidal fracture, and is whitish to yellowish in

[44] Lindgren, W., "Mineral Deposits," pp. 636, 640. McGraw-Hill Co., New York, 1919. Lindgren classes these deposits under those formed at intermediate temperatures and depths; he considers that the temperature of formation of the group including the Rio Tinto deposits ranged from 175° to 300° C., and the depth of formation from 4,000 to 12,000 feet.

color, depending on its copper content. It consists chiefly of pyrite, and Hereza states that it contains but 3 to 5 per cent. of silicate minerals. Some of it is banded. I did not see much of the banded ore, but Finlayson states [45] that it may occur locally in portions of the lodes, or occasionally make up the whole lode; and that in such cases the copper, lead, zinc and silica content is usually high. Collins [46] says that the banded structure in the compact pyrite is as a rule more pronounced in the small, narrow orebodies than in the wide lenses.

Disseminated Sulphide.—Disseminated sulphide flanks the massive ore; at its inner border it appears to merge gradually into massive sulphide, at its outer border it passes insensibly into pyritized porphyry. It occurs mainly in porphyry and is scarce or absent where slate forms the wall rock.[47] By way of example, at the east end of the great La Zarza pit, solid sulphide abuts against a narrow fringe of sericitized slate on the south or footwall side. (See Fig. 3.) But north of the solid sulphide, without sharp demarkation, is sericitized porphyry the bulk of which is sulphide in the form of veinlets, blebs, and scattered grains. Quartz veinlets are numerous. If one moves further northward, he sees that the amount of sulphide in the altered porphyry gradually diminishes. He passes through material that is almost identical with the protore of the American porphyry copper deposits and then reaches altered porphyry that contains no sulphides. Beyond this, the altered porphyry merges into relatively fresh rock.

This gradation from massive to disseminated sulphide is, I think, an important feature in any consideration of the origin of the deposit.

ORE MINERALS OF THE DEPOSITS.[48]

General.—A study of polished specimens of ore by means of the reflecting microscope equipped with nicol prisms reveals here-

[45] *Op. cit.*, p. 413.

[46] *Op. cit.*, p. 84.

[47] Collins, however, in his study of the smaller deposits, notes that sulphides impregnate slate. *Op. cit.*, p. 84.

[48] In the identification of the minerals, it gives me pleasure to acknowledge the kindness of Dr. M. N. Short of the U. S. Geological Survey, and Professors W. E. Ford and W. M. Agar of Yale University, in making check tests and determinations.

tofore unknown minerals for Rio Tinto, and also discloses features that bear on the origin of the deposits. The writer is also led to disagree with some of the previous investigators regarding the primary (hypogene) and secondary (supergene) origin of some of the minerals.

Numerous elements have been known in the Rio Tinto ores or metallurgical products. In addition to the common iron, sulphur, copper, zinc, lead, silver and gold, the rarer elements cobalt, nickel, selenium, and bismuth have been detected. The number of ore minerals recorded, however, is relatively few. Vogt [49] mentions pyrite, chalcopyrite, sphalerite, galena, and bornite. Finlayson [50] adds chalcocite and tetrahedrite, and Collins just mentions bournonite in addition to the common sulphides.

Vogt [51] says that the chalcopyrite and bornite are secondary minerals formed during the process of superficial alteration. Finlayson [52] also considers that chalcopyrite is secondary and has formed by replacement of pyrite. Collins argues that some chalcopyrite has been formed by "primary enrichment," but dismisses the subject of secondary enrichment with one sentence, without stating whether he considers any of it secondary. The bournonite of Collins has not been verified; it may be a mixture of minerals.[53]

The apparently simple mineralogy of the Rio Tinto ores proved, upon close examination, to be quite complex. Several unsuspected and rare minerals were identified and most of the previously detected elements can be assigned a mineral source.

Primary Minerals.—The study of the polished specimens discloses the following primary ore minerals: [54] Pyrite, chalcopyrite,

[49] *Zeit. f. prakt. Geol.*, vol. 7, pp. 241–254, 1899; Beyschlag-Vogt-Krusch, "Ore Deposits," vol. 1, p. 324.

[50] *Op. cit.*, p. 419.

[51] *Op. cit.*

[52] *Op. cit.*, p. 419.

[53] My study of the ore minerals indicates that, without microscopic examination, the determination of a mineral might be erroneous. I saw several specimens, apparently homogeneous to the naked eye, which proved under high magnification to be mixtures of minerals; analyses of such mixtures might approximate the composition of a mineral.

[54] Other minerals observed, in addition to the rock-forming minerals, are mag-

sphalerite, galena, arsenopyrite, tetrahedrite ($Cu_8Sb_2S_7$), enargite (Cu_3AsS_2), luzonite (Cu_3AsS_4), famatinite (Cu_3SbS_4), chalcostibite ($CuSbS_2$), whitneyite (Cu_9As), umangite (Cu_3Se_2),[55] hauchecornite ($(NiCo)_7$ (S SbBi)$_8$), ullmanite (NiSb S), and perhaps berthierite ($FeSb_2S_4$).[55] In addition three undetermined minerals were observed, visible only under high magnification and in particles too small for precise determination. Thus, source minerals for the elements cobalt, nickel, bismuth selenium and silver are now established. All the rare minerals mentioned above occur only in small particles that cannot be seen by the naked eye. It is rather striking that no bornite was observed.[56]

The *pyrite* has already been described. Microscopically, it shows nothing unusual except that highly polished surfaces inclose minute specks of the rarer minerals; and that in the massive ore crystal outlines are few, whereas in the disseminated ore they are common. The sparse crystals in the massive ore evidently represent an earlier stage of free growth; later they were surrounded by the growth of interlocking grains whose boundaries interfered with each other and prevented the formation of crystal outlines. In such irregular grain aggregates, minute specks of rock may be discerned.

The *chalcopyrite* claims especial interest because of the conclusion of Vogt and Finlayson that it is secondary, or supergene. My conclusion is that it is primary, or hypogene. Not one of the many specimens studied shows the characteristic features of supergene minerals. (Contrast Fig. 4 with Figs. 5, 6.) In fact, the chalcopyrite is itself veined by supergene covellite and chalcocite, proving that it is earlier than the supergene sulphides. (See Figs. 5 and 6.) Much of the massive chalcopyrite, however, was formed slightly later than the pyrite, but is contemporaneous in age with primary sphalerite, tetrahedrite, galena and

netite (as a rock mineral residual in the ore), quartz, sericite, chlorite, kaolin, siderite, barite, gypsum, copper carbonates, and some undifferentiated sulphates.

[55] The identification of the umangite and berthierite is uncertain, as they occur only in small grains. The microscopic properties, however, agree with these minerals.

[56] The bornite previously mentioned may have been iridescent tarnish.

quartz. The chalcopyrite has two general modes of occurrence, one as small grains intergrown with pyrite (see Fig. 4) and con-

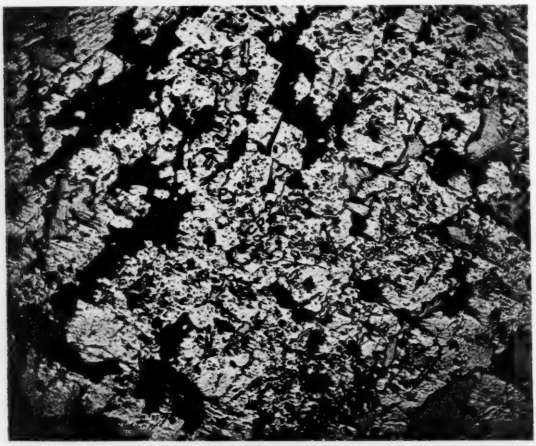

FIG. 4. Photomicrograph of polished specimen showing relations between primary pyrite (Py) and chalcopyrite (Cp). Chalcopyrite occurs within and around grains of pyrite. Note absence of veinlets of chalcopyrite cutting pyrite. Contrast with Fig. 5. Black specks in pyrite are rock matter. × 100.

tained within the massive pyrite,[57] and the other as larger masses occurring in bunches and veinlets that traverse the rocks or sulphides. The latter seem to have been simply a continuation of the earlier chalcopyrite deposition that kept up after the pyrite had ceased to form; consequently it overlapped the pyrite. It occupies about the same textural relation to the other ore minerals as does quartz in a granite. I saw nothing to support Collins's conclusion of a subsequent and separate enrichment of chalcopyrite. Chalcopyrite in other deposits is usually somewhat later in age than pyrite, where these two minerals occur together; the

[57] Since the two minerals are contemporaneous, and the pyrite is clearly primary, consequently the chalcopyrite is also primary.

resemblance to the chalcopyrite-pyrite relations of the Globe, Bisbee or Butte ores is striking. It is one of the last metallic minerals to come out of the metallizing solutions. Much of the chalcopyrite also includes microscopic specks of rock matter (see Fig. 4), and of other primary minerals such as arsenopyrite, enargite, sphalerite. Some of it, when viewed under crossed nicols with electric arc illumination, exhibits marked polysynthetic twinning.

Sphalerite is common throughout the ores, though it is mostly in small particles. It is contemporaneous in age with the chalcopyrite and exhibits mutual boundaries toward it. Scattered through some of it are the well-known pin points of chalcopyrite. Some of it is cut by veinlets of supergene covellite.

Galena is not of such frequent occurrence as sphalerite. It occurs with sphalerite or with chalcopyrite, and the three minerals appear to be essentially contemporaneous. Most of the galena is free from gneissic structure such as would be expected had the ore undergone any intensive shearing. The galena also is cut by supergene covellite.

Arsenopyrite, mostly in small particles, is fairly uniformly distributed in minute grains in the massive sulphides. It commonly has crystal outlines, and appears to have formed both slightly earlier and contemporaneously with pyrite. Unquestionably it is the mineral that contains most of the arsenic content of the ore.

Enargite, another arsenic mineral, is rare and was observed only as small specks of microscopic size in a few specimens. It is clearly a primary mineral and probably contemporaneous with chalcopyrite. It would account for but a small fraction of the arsenic present in the ore. A few specks of the pinkish variety, *luzonite,* also were observed.

Tetrahedrite (iron-tetrahedrite) occurs in bunches up to the size of walnuts, but it is difficult to obtain pieces of it free from other minerals. It is somewhat unusual in several respects, and its microscopic identification at first was puzzling.[58] Its color is

[58] My thanks are due to Dr. M. N. Short of the U. S. Geological Survey for making a careful check determination of one specimen of this mineral; also to Dr. W. M. Agar and Mr. D. Selchow of Yale University for wet tests of it.

different from ordinary tetrahedrite, and it gives etching tests that indicate freibergite, but wet tests show that it is entirely free from silver, and therefore is not freibergite. It has an unusually high iron content. Evidently little or no tennantite is associated with it, for its arsenic content is inappreciable.

Chalcostibite and *famatinite,* sulphantimonides of copper, are rare in any deposit, and in the Rio Tinto ore only a few small pieces were seen in half a dozen specimens. They were identified by their microscopic properties and by microchemical tests for antimony. Both minerals appear to be primary, but they are slightly later in age than sphalerite. The famatinite occurs in minute veinlets, and the chalcostibite in shapeless grains.

The *hauchecornite* was identified by its hardness, bronze yellow color, and etch tests, and by the characteristic nickel reaction with dimethylglyoxine. It is anisotropic. Only two pieces of it were seen; one is of irregular outline and the other is diamond-shaped. It occurs in pyrite and the two apparently are contemporaneous. This mineral may account for the presence of some of the nickel, bismuth and cobalt in the ore.

Ullmanite was noted in only one specimen. Its hardness was determined to be slightly less than that of pyrite, and its properties agree with those given by Davy and Farnham.[59] The presence of nickel was confirmed by the dimethylglyoxine test. It occurs with cubic outlines, embedded in pyrite and in chalcopyrite.

Whitneyite, another rare mineral, was identified in two specimens. In addition to diagnostic tests under the microscope, it yielded microchemical reactions for iron and arsenic.

Magnetite was observed as small particles scattered through the ores; it appears to be, not an introduced mineral, but an original constituent of the rock, preserved in the ore. Many of the particles are inclosed in rock silicates.

The microscopic tests of two undetermined minerals are recorded here for the benefit of others.

Mineral A.—Color, brownish mauve. No internal reflection;

[59] "Microscopic Examination of the Ore Minerals," McGraw-Hill Co., 1920.

surface smooth. Hardness (compared by "Becke" method with covellite and chalcopyrite) 2.5–3. Etching tests negative to all reagents except KCN, which gives a faint brownish tarnish that rubs clean. Under crossed nicols is weakly anisotropic. This mineral is rather common in the ore but was seen only as minute specks.

Mineral B.—Violet. No internal reflections. Surface slightly rough. Hardness slightly higher than chalcopyrite or sphalerite. Etching tests negative to all reagents. Anisotropic. Can be distinguished from adjacent sphalerite. Occurs with chalcopyrite and pyrite. Particles are too small to yield material for microchemical reactions.

Secondary Sulphides.[60]—Covellite and chalcocite occur as unmistakable supergene or secondary minerals.[61]

The *covellite* veins or rims other minerals, notably chalcopyrite (see Fig. 5), but also replaces sphalerite, pyrite, galena, tetrahedrite and famatinite. It prefers to replace chalcopyrite rather than pyrite; veinlets traverse chalcopyrite but terminate at pyrite boundaries, and blebs of chalcopyrite have been almost completely replaced (see Fig. 6), whereas adjacent pyrite grains have hardly been touched.

The covellite is an unusually pleochroic variety. This is clearly evident in plane polarized light, and under crossed nicols a high order of birefringence colors are obtained. This covellite is seen under crossed nicols to be made up of quite small, irregular interlocking grains; lathlike crystals, so common with primary or hypogene covellite, are lacking.

The *chalcocite* occurs in the massive and sooty forms. In its relations to the other minerals it resembles covellite except that, in chalcopyrite, it is not so abundant as covellite. The massive chalcocite contained in chalcopyrite has an unusually bluish color under the microscope, so much so that in ordinary reflected light it may be mistaken for covellite; under crossed nicols, however, the distinction between the two is clear, as the chalcocite lacks

[60] The secondary oxidized minerals will be referred to under the next heading.

[61] Some of the evidence for their secondary character will follow, under "Secondary Enrichment."

the high birefringence colors of covellite. The deep bluish color is similar to that of the blue chalcocite of Kennecott, Alaska; probably it is due to the same cause, namely, dissolved covellite.[62]

The chalcocite that replaces the iron-tetrahedrite has the usual chalcocite color, but its properties and etch tests are slightly different from ordinary chalcocite, so that I did not feel assured of its identification until I received the benefit of a check determination kindly made by Dr. M. N. Short of the U. S. Geological Survey.

The chalcocite and covellite have associated with them some cuprite, malachite and iron oxides.

OXIDATION AND ENRICHMENT.

I have little first-hand knowledge, other than mineralogical, of the superficial alteration of the Huelva ores. The reader is therefore referred to the literature.[63] Although it has long been recognized that there was secondary enrichment of the Huelva ores, the literature is extremely vague in respect to details of enrichment, and the fascinating subject of gossan formation has been treated only along broad lines. Details of the nature of the gossan, its mineralogical, physical and chemical character, and the derivation of certain kinds of limonite from certain classes of sulphide, or the contrast of transported and residual limonite, remain a broad subject for future field and laboratory study.

The Gossans.—The gossans are clearly of two types—those formed *in situ,* or true gossans, and transported iron oxides, or "pseudo-gossans." The latter are without sulphide roots; the iron came from oxidizing orebodies near by, was transported, and deposited as bog iron ore. The iron deposits of Mesa de los Pinõs and Cerro de los Vacas belong to this group. The explanation of Phillips,[64] who investigated them, is in keeping with

[62] Alan Bateman and D. H. McLaughlin, "Geology of the Ore Deposits of Kennecott, Alaska," ECON. GEOL., vol. 15, pp. 1–80, 1920.

[63] Finlayson, ECON. GEOL., vol. 5, pp. 403–437, 1910. Hereza, Guide Book A–3, 14th Int. Geol. Congress. Vogt, "Ore Deposits" (Beyschlag-Vogt-Krusch), vol. 1, pp. 315–327; *Zeit. f. prakt. Geol.,* vol. 7, p. 250, 1899. De Launay, "Gites Mineraux et Metallifères," vol. 2, pp. 670–675, Paris, 1913.

[64] J. A. Phillips, "Ore Deposits," p. 15. Macmillan Co., 1884.

the physiographic history of the region, namely: These iron oxides were precipitated in a swampy lake, along with vegetation, and subsequent denudation left them as erosion remnants that cap these two hills. Plant remains found in the deposits show their bog origin,[65] and their unconformable position on a non-sulphide floor proves that they were transported.[66]

This occurrence is but another link in the chain of physiographic history previously sketched. The period of peneplanation afforded the requisite conditions for accumulation, in low-lying parts, of oxides derived by oxidation from the lodes of Cerro Salomon and Cerro Colorado. The latter must have remained as monadnocks, for they are higher than the tops of the iron ore deposits. The dissection of the peneplain left, as hilltop remnants, the iron ore bed of Mesa de los Pinõs. It is now a steep-sided mass 3,000 feet long by 300 feet wide, with a depth of 25 feet. This would indicate that the sulphide deposits were subject to oxidation, and therefore to conditions favoring enrichment, during the long period of time involved in peneplanation. And this oxidation must have continued throughout the dissection of that peneplain into the present land forms.

We can reconstruct, then, a mental picture of the events in the development of the land forms as they affected oxidation and

[65] According to Phillips, mosses, with leaves, acorns, seeds, and cones of oak and pine belonging to species still growing in Spain and considered of recent age, formed a peat-moss.

[66] In this connection Rio Tinto (the river) is of interest to the geologist and chemist, and illustrates iron being transported and deposited today. Just below the deposits it has an unusual inky green color, owing to the abundant ferrous sulphate that enters it from the precipitating launders (where the copper sulphate solutions from the heap leaching have their copper precipitated by iron). Farther down, the deep green color persists in the center, but marginal still-water areas become reddish yellow from ferric sulphate. Aeration in rapids speeds oxidation; the water becomes redder. Gradually it changes to a yellowish brown, and where a tributary laden with lime salts enters its middle reaches the color change is abrupt; the change from a ferrous to a ferric state being accelerated. In its lower reaches the oxidation to ferric hydroxide and limonite is complete; the river has a deep brownish maroon color, and is like a mass of flowing limonite. Evidently limonite is deposited where the river enters the salt water of the estuary, since the estuary waters are clear. A conglomerate cemented by iron oxide at Niebla, noted by Dr. H. G. Ferguson, may represent an earlier stage of iron oxide deposition from the Rio Tinto, when its iron content was obtained from the ore deposits by natural processes.

enrichment: Originally the surface stood hundreds of feet higher than at present; gradually it was lowered by erosion until the tops of sulphide bodies cropped out on a rolling land; rain and atmospheric gases decomposed the sulphide tops. They, with disintegrated wall rock, were swept away by rains and streams; the surface was continually lowered, reaching farther and farther down into sulphide bodies, past the bottom of some, into the heart of many, and near the tops of others. The land became smoother, the water table approached the surface, and the streams moved more sluggishly, since their fall toward the sea became less. The load they could carry was small; erosion was slowed up and the surface approached a peneplain.[67] But the landscape was not entirely flattish; for harder Cerro Salomon and Cerro Colorado stood up above it, and from the decomposing orebodies on their sides iron-laden waters moved towards the swampy ground near by. A layer of iron oxide was built up; this thickened until many tens of feet had accumulated from the wastage of the sulphide masses. The region was uplifted; the senile streams, rejuvenated, eroded with youthful vigor and cut deep valleys into that old peneplain and locally depressed the water level. The Rio Agrio even cut back through the iron bed and carried most of it away, but an uneroded patch or two were left perched on either valley side to form the Mesa de los Pinõs, cut off by the valley from the continuation of itself, the Cerro de los Vacas. The latest uplift caused the streams to cut notches in the broad valley bottoms and to depress the water level still further. Meanwhile the copper in the eroding sulphide bodies dissolved and trickled down beneath the zone of oxidation and was added to that below, dwindling in amount from the bottom of oxidation downward.

This bog iron from the "pseudo-gossans" is hard, compact, has a steely luster, and is distinctly banded. Steel gray bands alternate with deep reddish brown bands. Under the polarizing reflecting microscope two distinct varieties are visible—one white, and the other gray-white with a brownish or reddish internal re-

[67] There is a possibility that a later peneplain truncated the iron ore beds prior to the formation of the mature valleys.

flection under crossed nicols. The first yields no water in the closed tube, the second yields a little water. The minerals are hematite and goethite. The goethite bands are practically homogeneous, but the hematite bands are a mixture of hematite and goethite, with fragments of goethite surrounded by hematite, and angular fragments of smooth pure hematite surrounded by rougher hematite filled by inclusions.

The gossans formed *in situ* include most of the croppings of the district; some, according to Finlayson [68] have little or no ore beneath them and are the oxidized roots of previously existing sulphide bodies. Most of the gossans overlie sulphides at a depth of 20 to 90 meters.[69] Some of the gossans are large enough and high enough in iron content to constitute ores of iron.[70]

Within the zone of oxidation, the removal of the soluble constituents and the conversion of iron-sulphide to iron oxides was complete. Residual copper minerals are mineralogical curiosities.

The bottom of the zone of oxidation is sharply demarked from the underlying sulphides. The bottom contour is so regular it must have been determined by a water table. But it is not related to the present water table, and it is discordant with the present topography; it was formed during an earlier topographic stage, when the water table stood higher. And the water table must have been a shallow one, since the oxidized zone is relatively thin.[71] This suggests the peneplain stage rather than the broad valley stage,[72] since the former usually are accompanied by shallow water tables that prevent deep oxidation and enrichment.

[68] *Op. cit.*, p. 409.

[69] Stephen Vibran, *Tr. Inst. Min. and Met.*, vol. 31, p. 108, 1921; Vogt states (*Zeit. f. prakt. Geol.*, vol. 7, p. 249, 1899) that the average depth of the gossan is about 20 meters, and Finlayson (*op. cit.*, p. 409), 30 meters.

[70] As to the precise mineralogical character of this type of gossan, my specimens are too few to be either representative or dependable, and the literature adds nothing other than that they are "limonite." My own specimens contain nothing but goethite.

[71] Thin oxidized zones may also be formed with a deep water table where so much pyrite is present that the available oxygen is utilized to form iron oxide before it can reach the water table.

[72] It is possible that the bottom of the zone of oxidation was controlled by the

The latest uplift evidently was too rapid and recent for oxidation to keep pace with it, for the bottom of the oxidized zone is now stranded above the present water level. The sporadic deeper oxidation must have taken place while the present valleys were being excavated.

Secondary Enrichment.—The secondary sulphide enrichment has been described by Gonzalo y Tarin,[73] Vogt,[74] Phillips,[75] Finlayson,[76] De Launay,[77] Beck,[78] and others. Most of the literature deals only with the downward decrease in copper content, but Finlayson treats somewhat of the mineralogy and processes. Vogt [79] states that gold and silver in places are richly concentrated, in layers frequently only a few centimeters thick, at the bottom of the oxidized zone, and that enriched sulphides extend 50 meters or more below this. He says that this cementation zone (secondary sulphide zone) contains chiefly bornite and chalcopyrite derived by alteration of cupriferous pyrite [80] which was converted by replacement processes, first to chalcopyrite and afterwards to bornite.

Beck,[81] following Vogt, also states that the pyrite has been secondarily enriched to chalcopyrite and bornite to form rich supergene ores.

De Launay [82] shows that the copper content gradually diminishes downward to about 150 meters, and states that chalcopyrite,

water table that underlay the broad valleys which incise the peneplain. This does not, however, seem probable, since the accompanying water table must have had considerable relief, particularly around the mines, and the bottom of the zone of oxidation is in general rather level.

[73] *Op. cit.*

[74] *Op. cit.*

[75] Phillips, J. A., "Ore Deposits," p. 15. Macmillan, 1884.

[76] Finlayson, A. M. ECON. GEOL., vol. 5, pp. 403–437, 1910.

[77] De Launay, "Gites Mineraux et Metallifères," vol. 2, pp. 670–675, Paris, 1913.

[78] Beck, "Lehre von den Erzlagerstätten," vol. I., pp. 143–149, Berlin, 1909.

[79] *Op. cit.*, pp. 321–322.

[80] Cupriferous pyrite is now known to be a mixture of the minerals pyrite and chalcopyrite.

[81] *Op. cit.*

[82] *Op. cit.*

bornite, chalcocite and native copper have altered the pyrite to form the rich secondary zone.

Finlayson [83] states that the top meter or more of the sulphide zone contains leached pyrite with only traces of copper. I have observed similar impoverishment at Morenci, Arizona; Bingham, Utah; Cananea, Mexico; and other places; it has been described frequently in the literature. Finlayson says that beneath this is the zone of enriched sulphides averaging 4–7 per cent. of copper, extending with diminishing grade to a depth of 50–60 meters below the gossan. Finlayson and Wetzig [84] believe there is a direct relation between depth of enrichment and thickness of the overlying gossan. Finlayson concludes [85] that chalcopyrite and chalcocite with a little bornite are the chief products of enrichment, but that "strings of argentiferous galena, with occasional tetrahedrite and other silver-bearing ores have been abundant as secondary products in some lodes." He recognizes two classes of enrichment; one a replacement by chalcocite in the leaner ores, and the other a formation of secondary chalcopyrite with subordinate chalcocite, from the richer ores.

My own investigation, confined chiefly to the specimens that I collected, leads to a different conclusion. The only secondary sulphides I recognized are chalcocite and covellite; bornite was not seen; the tetrahedrite and galena, I believe, are primary; and I think all the chalcopyrite is primary. The enrichment of the Huelva ores is, in my opinion, of the usual simple type found in dozens of other copper deposits; namely, replacement by chalcocite and covellite of chalcopyrite and pyrite and to a lesser extent of sphalerite, galena, tetrahedrite, and other minerals.

The enriching solutions attacked chalcopyrite more readily than the other sulphides and usually it is covellite rather than chalcocite that replaces it. Sphalerite and galena, also, are more readily replaced by the secondary sulphides than are pyrite or tetrahedrite. The amount of covellite or chalcocite that has re-

[83] *Op. cit.*

[84] *Zeit. f. prakt. Geol.*, vol. 14, p. 180, 1906.

[85] *Op. cit.*, p. 411.

placed pyrite is greater, however, than that derived from sphalerite and galena, because the latter are scarce.

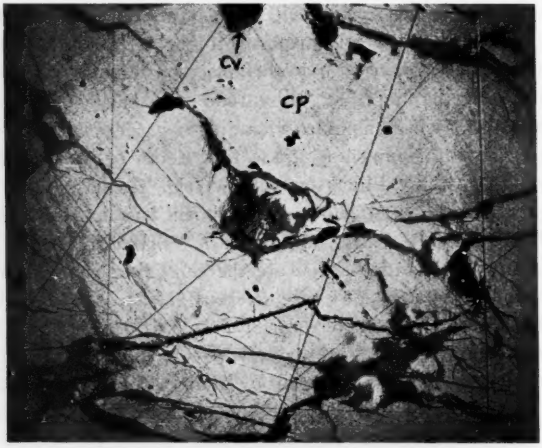

FIG. 5. Photomicrograph of polished specimen showing incipient stage of enrichment with veinets of covellite (Cv) cutting chalcopyrite (Cp) and forming rims about quartz (black), proving that chalcopyrite is earlier than covellite. × 90.

Of the two secondary (supergene) sulphides, covellite is less abundant than chalcocite, though it is present in sufficient quantity to make an appreciable enrichment of the ore, even though chalcocite were absent. The covellite veinlets that criss-cross or rim chalcopyrite grains (Fig. 5) may widen by replacement so that most of the chalcopyrite is altered to covellite (with subsidiary chalcocite) and only small residuals of unreplaced chalcopyrite remain. (See Fig. 6.) At this advanced stage of replacement, pyrite also is attacked, whereas in the incipient veinlet stage of replacement the pyrite is not touched. In the deeper ores, with waning enrichment, the covellite gives way to chalcocite in replacing chalcopyrite. (Fig. 7.) The covellite is clearly of later

age than the chalcopyrite and pyrite; it occurs only along cracks or other minute openings, and this is characteristic of supergene sulphides.

FIG. 6. More advanced stage of enrichment than Fig. 5. Covellite (Cv) veinlets have widened by replacement of chalcopyrite (Cp), leaving unreplaced residuals of chalcopyrite included in covellite. Pleochroic covellite gives mottled appearance. Undetermined pinkish mineral (?) in crack.

The chalcocite, like the covellite, follows cracks in the pyrite and chalcopyrite, and may form ragged embayments into the primary sulphides, or occur as fine threads that cut the grains of earlier minerals (Fig. 7), or encircle individual grains. The coalescence of veinlets at the expense of the pre-existing sulphides may leave nuclei of these minerals included in chalcocite. The enrichment was never observed to be so complete that residuals of the replaced pyrite could not be found, nor has replacement by chalcocite advanced to such a stage that large masses of chalcocite have been formed.

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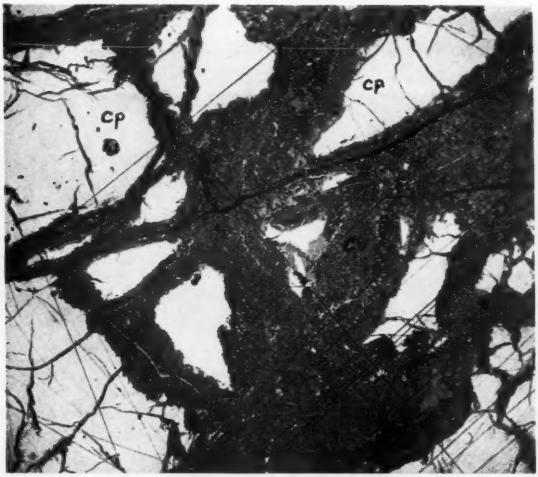

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Chalcocite also replaces chalcopyrite in preference to pyrite, and in many cases small chalcopyrite grains or veinlets in the original sulphide ore have been so thoroughly replaced by chalcocite that the ore appears to be simply a mixture of chalcocite grains in pyrite, and the parent mineral is not suspected except under high powers of the microscope.

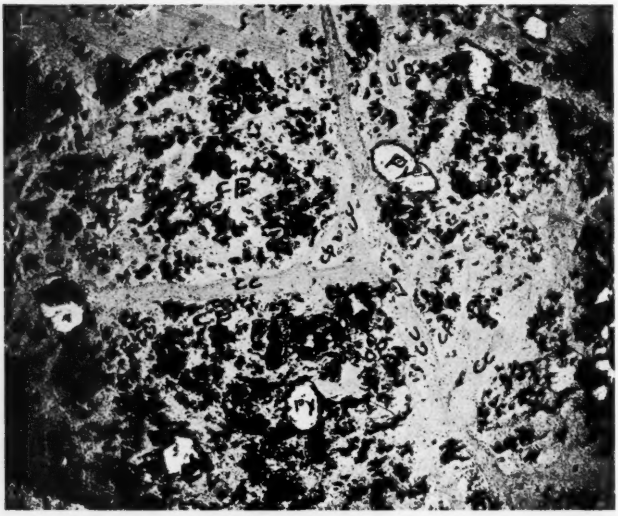

FIG. 7. Photomicrograph of polished specimen of grain of primary chalcopyrite (Cp) veined and being replaced by supergene blue chalcocite (Cc). Chalcopyrite contains many inclusions of rock matter (black). Chalcocite is "dusty" from included specks of quartz.

The degree of supergene sulphide enrichment in the Rio Tinto ores is not nearly so far advanced as in the enriched ores of most of the American copper deposits such as, for example, Utah Copper, Miami, Ray, or Ely. In these deposits the proportion of the total original sulphides that has been replaced by the richer secondary copper sulphides is many times greater than at Rio Tinto.

For example, it may be calculated that the average Rio Tinto primary ore contains from 3 to 6 per cent. chalcopyrite, and that to produce the average mine run of enriched ore [86] only 3 to 8 per cent. of the total sulphide need be converted to chalcocite and covellite. The scattered grains of chalcopyrite alone need be replaced by chalcocite and covellite to yield a copper content comparable with that of large volumes of the enriched ore mined in the past. This would mean that the primary copper content would be just about doubled. In most of the American enriched copper deposits the primary copper content has been increased by enrichment from 4 to 12 times, and from 20 to 60 per cent. of the primary sulphides have been changed to secondary sulphides. Had the enrichment at Rio Tinto been of comparable completeness, the ores there would contain from 14 to 44 per cent. copper. The actual amount of secondary enrichment at Rio Tinto has thus not been large, though its economic importance has been great.

The small copper enrichment is probably due chiefly to the fact that in the latter part of the peneplain stage the water table was shallow, and prevented deep oxidation; therefore the enrichment was small. The later uplift was too rapid for oxidation to keep pace with erosion; the oxidized zone was cut into instead of being increased in downward extent, for it is now stranded above the water table. Consequently little copper was released for enrichment. The massive pyrite is probably a contributing factor in retarding enrichment, for it prevents rapid and deep oxidation. Oxidizing waters cannot penetrate far into it before their available oxygen is used up. Also such waters must oxidize great quantities of pyrite to dissolve a little copper.

The secondary chalcocite and covellite were observed to form only as replacements of earlier sulphides; they are thus similar to the secondary sulphides of practically all enriched copper deposits.

These two minerals, as well as the associated unreplaced primary sulphides, are in turn undergoing further oxidation where the zone of oxidation is encroaching on the sulphide zone below.

[86] Excluding the high-grade copper ore at the top of the enriched zone.

Threadlike veinlets of cuprite, iron oxides, malachite and sulphates ramify through all the sulphides along cracks and grain boundaries. Some of the chalcocite is filled by iron oxides.

DISCUSSION OF ORIGIN.

The origin of the great Huelva masses of nearly pure sulphide has long been a subject of controversy among geologists.

Previous Ideas.—The earlier investigators noted that the deposits lay in slates parallel to the bedding, that there were parallel layers of slate in the deposits, and that the ore was banded. From this they concluded that the pyrite was a sedimentary bed, later folded and pinched into lenses. Römer,[87] J. H. Collins [88] and Stelzner [89] subscribed to this view. But its most vigorous supporter was Klockmann,[90] who considered the pyrite to have been deposited in sea mud as concretionary masses, and impregnated by copper released from what he called lavas. These ideas caused closer study of the rocks themselves, and some of them were found not to be sedimentary. Klockmann later noted a close connection between pyrite and porphyry, as did also Wetzig,[91] who was the last to support a sedimentary origin. This theory, however, was not the only one advanced, for Gonzalo y Tarin [92] and De Launay [93] early held that they were cavity fillings from ascending solutions; and Vogt in 1899 [94] said the deposits were pneumatolitic, formed as a direct effect of the porphyry intrusions. Still later Schmidt and Preiswerk [95] supported

[87] Römer, Ferd., *Neues. Jahrb. f. Min.*, 1873, p. 256.

[88] Collins, J. H., "Geology of the Rio Tinto Mines," *Quar. Jour. Geol. Soc.*, vol. XLI., p. 245, 1885.

[89] Stelzner, "Die Erzlagerstätten," p. 357, 1906.

[90] Klockmann, F., *Akad. d. Wiss. Berlin*, vol. XLVI., 1894; Spanisch-Portugiesische Kiesvorkommen, *Zeit. f. prakt. Geol.*, vol. III., p. 35, 1895; *idem*, vol.. X, p. 113, 1902; *idem*, vol. XII., p. 225, 1904.

[91] Wetzig, B., "Beitrage zur Kenntniss der Huelvaner Kieslagerstätten," *Zeit. f. prakt. Geol.*, vol. XIV., p. 173, 1906.

[92] Gonzalo y Tarin, *Bol. Comp. Mapa Geol. España*, Madrid, 1886–1888.

[93] De Launay, *Ann. de Mines*, Ser. 8, vol. XVI., p. 407, Paris, 1889.

[94] Vogt, J. H. L., "Das Huelva Kiesfeld," etc., *Zeit. f. prakt. Geol.*, vol. VII., p. 241, 1899.

[95] Schmidt, C., and Preiswerk, H., *Zeit. f. prakt. Geol.*, vol. XII., p. 225, 1904; *idem*, vol. XIV., p. 261, 1906.

an epigenetic origin, for they found pyrite cutting across the schistosity of the slate. This obviously could not be reconciled with a sedimentary origin; the deposits clearly are later than both the laying down of the slate beds and their subsequent folding.

Up to this time the discussions were concerned entirely with determining whether the deposits were of sedimentary or epigenetic origin, and little thought was given to the nature of the epigenetic process. Then, in 1905, J. W. Gregory,[95a] as a result of his conclusion that the Mount Lyell deposits of Tasmania had been formed by metasomatic replacement, inclined to a similar view for the Rio Tinto deposits. But when the Beyschlag-Vogt-Krusch textbook [96] made its appearance in 1910, the Huelva ores were listed under "intrusive Kieslagerstätten," and the authors considered them to be magmatic segregations similar to corresponding deposits in Norway.

Finlayson's important paper [97] in 1910 offered strong evidence for a replacement origin by hot solutions resulting from the magmatic differentiation that gave rise to the igneous intrusions.

In 1921, J. Morrow Campbell, in reply to discussion of his paper [98] indicated that he regarded the Huelva deposits as molten segregations.

The next important contribution was the detailed petrographic paper by H. F. Collins [99] in 1922. He supported vigorously the replacement origin of the Huelva deposits, and presented additional evidence to sustain his contention. He considered that the solutions emanated from an underlying magma reservoir which supplied the igneous rocks, and replaced the slate and porphyry along shear zones. The printed discussions of Collins's paper show that his ideas were not entirely accepted; several contributors favor a magmatic injection origin.

[95a] Gregory, J. W. Mount Lyell Mining Field, etc. *Tr. Aust. Inst. Min. Eng.*, vol. IX., p. 165, 1905.

[96] Beyschlag-Vogt-Krusch, "Lagerstätten der nutz. Mineralien und Gesteine," p. 321, Stuttgart, 1910.

[97] *Op. cit.*

[98] Campbell, J. Morrow, discussions of "Origin of Primary Ore Deposits." *Trans. Inst. Min. & Met.*, vol. 30, p. 87, 1921.

[99] *Op. cit.*

A swing back toward a magmatic injection hypothesis is noticeable in the papers prepared for the Fourteenth International Geologic Congress, and the discussions that took place in Madrid. In the official guide book [100] of the Huelva district it is stated that a metasomatic origin is considered "neither likely nor reasonable" since "in the first case, the masses (pyrite) show a great homogeneousness with the total absence of gangue; and in a metasomatic process . . . the skeleton of the substituted rocks would always be visible. In the second case, metasomatism, common and natural in all soluble rocks such as limestones, is contrary to the laws of thermochemistry when dealing with rocks so stable and insoluble as slates."

There are, however, so many well established instances of replacement of slate and other equally refractory rocks that the above statement can hardly be accepted as a basis for the elimination of a replacement process. Senor Hereza [101] inclines toward a modified magmatic injection theory, the details of which are somewhat vague and are not entirely clear to the writer. A. Broughton Edge [102] presented a paper at Madrid in which he concluded that the sulphide masses were of magmatic origin, having been injected into their present positions in the form of a tenuous pyritic matte.

Andre Demay [103] also pleaded for an igneous origin, and considered on petrographic grounds that the pyritic bodies were formed before the final consolidation of the porphyry. Unfortunately the details of the arguments of Edge and Demay are not available.

Zavaritsky, in his paper [104] on "Les Gisements de Pyrite de la Russie," presented at Madrid, concludes that the Ural pyrite masses are of magmatic origin. Though he does not discuss the

[100] "Metalliferous Deposits of Linares and Huelva," by J. Hereza and A. de Alvarado, 14th Int. Geol. Cong. Guide Book A–3. Inst. Geol. de Espāna, Madrid, 1926.

[101] *Op. cit.*, p. 104.

[102] "Pyritic Orebodies of Southern Spain and Portugal," Resumen de los Communicaciones Annunciados, Cong. Geol. Int. 14th Sesion, p. 85. Madrid, 1926.

[103] "Sur la Genèse des Gisements de Pyrite de Huelva," *Idem*, p. 93.

[104] *Idem*, p. 9.

Huelva deposits, he includes them in the same group as the Ural deposits.

Most of those who discussed the above papers at Madrid spoke for a magmatic origin, and the Continental geologists in particular favored a magmatic injection hypothesis.

The Problem of Origin.—The chief problem in the origin of the Huelva deposits is how the great sulphide masses attained their present positions. Were they laid down as sediments; were they fillings of yawning cavities that receptively awaited an influx of solutions or matte; were they forcibly injected as a sulphide magma that spread the rocks apart; or were they formed by slow solution of the country rock and simultaneous deposition of sulphides, *i.e.* replacement?

The sedimentary origin has long ago been justly discarded, since the deposits cut across slate bedding and occur in igneous rocks. Nor does the filling of previously existing cavities seem likely, for in the first place it is improbable that huge open cavities were ever formed in such resistant rocks; and in the second place such cavities, if once formed, could hardly remain open in yielding slate at the depths at which the Huelva deposits were formed. We may direct our attention, then, to the two favored hypotheses—igneous injection and replacement.

It is my belief that the huge sulphide masses are not magmatic injections or segregations *in situ,* but were formed by metasomatic replacement of the country rock through the agency of hot waters, presumably of magmatic derivation. This conclusion supports that of Gregory, Finlayson, and Collins.

Objections to Magmatic Origin.—Some of my objections to a magmatic origin are: First, the magmatic injection hypothesis implies that a magma (of remarkable sulphide purity) must have made way for itself by pressing apart the enclosing rocks. Since the deposits are lenses of a maximum width of 820 feet, there should be evidence, if the rocks were forced apart, of squeezing or contortion at the sides of the lenses, and of a curving in of the strata toward the thin end of the lenses. I did not observe such features, nor have they been recorded in the literature. There

has been some shearing of the walls of the deposits, but this has been attributed to later shearing stresses. On the other hand, some of the orebodies abut against truncated ends of slate beds the prolongation of which would carry them into the place now occupied by ore (see Fig. 3). They have not been bent aside; they have been removed. It is my opinion that practically all the rock that occupied the space where the orebodies now lie has actually been removed, and not pushed aside. Such removal is not consistent with an injection hypothesis unless there had been magmatic stoping. And there is no evidence of a marginal rubble, or disarranged included blocks, such as would be expected had stoping taken place. The blocks of rock inclosed by ore are shown by Collins to preserve the attitude of the wall rocks—a feature diagnostic of replacement and not of magmatic stoping. Nor is there evidence of resorption of huge masses of rock by a sulphide magma.

Second, it has been shown previously that the massive and disseminated sulphides are inseparable; an explanation for one must account also for the other. Consequently, if the massive sulphide is an igneous injection, then the associated marginal disseminated sulphide must likewise be an igneous injection. But this is untenable; igneous injections have not been found by geologists to give rise to large bodies of disseminated sulphides such as flank the Huelva pyrite masses.

Third, some ore follows shears in the porphyry, but the ore itself is not sheared. This can be seen in the field and under the microscope. Small shreds of cleaved porphyry contain little unbroken veinlets of sulphides parallel to the shears. Also veinlets of sulphide cut indiscriminately across all the rock minerals of the porphyry; consequently the sulphides are later than both the consolidation of the porphyry and its shearing. The time interval separating them was at least long enough for the porphyry to crystallize and to be sheared.[105] Therefore, the sulphide did not segregate from crystallizing porphyry, nor was it an in-

[105] Also, since the ore is later than the diabase, it cannot be part of the earlier porphyry intrusion, if Finlayson is correct in his conclusion that the diabase is the latest intrusive.

jection, as claimed by Demay,[106] prior to the final consolidation of the adjacent porphyry.

Fourth, the microscopic texture of the ore is not that of a cooled igneous rock.

Fifth, there is no evidence of contact metamorphism such as would be expected if there had been magmatic sulphide intrusions. On the contrary, the halo of intense seritic alteration surrounding the ore is typically hydrothermal.

Replacement Origin.—On the other hand, the association of massive and disseminated sulphide, the microscopic and field relations of ore and rock, the structure of the ore, its mineralogy, and the associated rock alteration, favor a replacement origin for the deposits. These points will be discussed in order.

The marginal disseminated sulphide may be seen both in the field and under the microscope to occur as isolated grains and veinlets that cut across, embay, and replace individual grains of the porphyry. Single sulphide particles have eaten into and have replaced parts of contiguous quartz and feldspar grains (Fig. 8). Cracks filled by sulphide do not match on opposite sides, but have been enlarged at the expense of the rock minerals, and the contact between sulphide and rock is a wavy line of small irregular embayments (Fig. 4). One cannot conceive of cracks with such irregular, intricately wavy boundaries being formed by rupture and later filled by ore. Veinlets that cross alternating grains of quartz and feldspar or other minerals widen out considerably in the feldspar areas and shrink in width where they cross less replaceable quartz, a feature characteristic of replacement. Two instances were observed under the microscope where sulphides had replaced and preserved the outlines of feldspar phenocrysts. In some cases replacement had proceeded outward from intersecting veinlets to such an extent that inter-veinlet areas of rock became diminished to minute rock inclusions. In much of the disseminated ore, the pyrite is in well-marked cubes that cut across grain boundaries of the rock silicates. They are not cubes that grew first and then had later rock silicates moulded against them, but cubes that grew after the rock silicates had interlocked,

[106] *Op. cit.*, p. 93.

and at the expense of those silicates (Fig. 8). It is such structures as these that I interpret to indicate replacement.

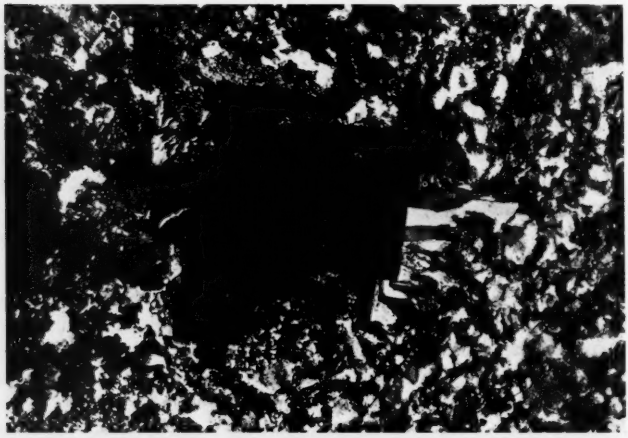

FIG. 8. Photomicrograph of thin section under crossed nicols showing pyrite crystal (black) truncating feldspar crystal, quartz and groundmass of porphyry, interpreted as evidence of replacement. × 100.

Nearer the massive sulphide, thin sections and polished sections show that the small veinlets are wider and the sulphide centers are bigger and more thickly dotted. Small rock residuals in the ore become more numerous. Many of them are plate-like inclusions of sheared porphyry. It is clearly a more advanced stage of the same type of structures observed in the disseminated ore.

Within the massive sulphide itself, thin sections tell nothing, but polished specimens observed with reflected polarized light show many rock inclusions with irregular embayed outlines (Fig. 4). They appear to be residuals of original rock left by incomplete replacement, and are merely more advanced stages of the structures described above. Most of the pyrite when well polished has a very rough surface; ghostlike outlines are visible

all through it, and when examined with an oil immersion lens, these are resolved into areas of minute specks of rock matter. They are remnants of rock that have been all but completely replaced by sulphides. The pyrite grains with cubic outlines, however, are smooth and unflecked; they are free from inclusions.

Another bit of microscopic evidence suggests replacement. A narrow band of included porphyry with magnetite grains in it was seen on either side of intercepting pyrite, but its ghostlike outline could be followed through, and it was marked by magnetite grains. They are residuals that resisted replacement by pyrite, while the rock containing them succumbed.

The banded ore also indicates replacement. Field and microscopic observations show that it is not the result of post-ore shearing or later recrystallization, or of original flow structure of a sulphide magma, but is a structure inherited from the sheared rock that is replaced by sulphide. Stringers of sulphide parallel to the walls of the lode alternate with thin parallel plates of chloritized rock or unreplaced quartz grains of the porphyry. Finlayson states [107] that such banded ore passes over gradually into non-banded massive sulphide. He was able also to trace "slaty ore" into massive sulphide on the one side, and into banded slate and ore on the other side.[108] And Collins says [109] that progressive stages of replacement may be traced from pyritous schist to massive sulphide which retains the original banded structure of the schist from which it was transformed.

The unsupported inclusions of country rock in ore, or the "horses" of waste with frayed and embayed edges, described by Finlayson [110] and Collins [111] must be considered indicative of replacement.

The strongest indication of hydrothermal action is the conspicuous aureole of sericitic alteration that flanks the ore. Sericitic alteration is characteristically the work of hot waters. My

[107] *Op. cit.*, pp. 414–415.
[108] *Op. cit.*, p. 409.
[109] *Op. cit.*, p. 84.
[110] *Op. cit.*, p. 414.
[111] *Op. cit.*, p. 86.

own experience, and that of others, with many copper deposits of the North American Continent, is that sericitization (and to a less extent, chloritization) is an almost universal companion of epigenetic ore deposits formed in rocks other than limestone. And the intensity of the alteration is commonly an indication of the magnitude of hydrothermal action and of sulphide deposition. In this respect the Huelva deposits resemble other copper deposits with associated sericitic alteration which are considered to have been formed by hot waters.[112]

The mineralogy also throws some light on the origin. There is in the deposits an absence of gangue composed of minerals of igneous rocks, and the metallic and gangue minerals are those that have come to be considered by geologists as minerals of water formation. Pyrite, chalcopyrite and arsenopyrite are not significant, but galena, sphalerite, tetrahedrite, enargite, famatinite and chalcostibite are characteristic of aqueous solutions, as is also barite. The last-mentioned metallic minerals are all of the same period of formation (though of different sequence) as the pyrite, chalcopyrite and arsenopyrite. Consequently it is likely they were all formed from aqueous solutions.

The striking similarity in the mineralogy, accompanying rock alteration, and mode of occurrence of the Huelva orebodies with other deposits of replacement origin, is also suggestive that they were all formed by a similar process. For example, the deposits of Mount Lyell, Tasmania; Rammelsberg, Germany; Shasta County, California; Kyshtim, Russia; and Tyee, British Columbia, have already been grouped [113] with the Huelva deposits. To these might be added the Flin Flon deposit of Manitoba [114]; Mandy Mine, Manitoba [114]; Eustis Mine, Quebec [114]; United

[112] If hot water was the ore carrier, then deposition in open cavities, as well as replacement processes, must be given consideration. But the arguments presented favor replacement; it has been shown that open cavities seem improbable, and the ore shows no crustification, comb structure, open vugs, or other criteria diagnostic of cavity filling.

[113] W. Lindgren, "Mineral Deposits," p. 636. McGraw-Hill Co., 1919.

[114] Hanson, George, "Pyritic Deposits in Metamorphic Rocks," ECON. GEOL., vol. 15, pp. 574–609, 1920.

Verde Mine, Arizona [115]; Ellamar Mine, Alaska [116]; Besshi Mine, S. W. Japan [117]; Hegashiyama Mine, Japan [118]; and probably the Hitachi Mines, Japan.[119]

All these deposits are characterized by:—Large bodies of massive pyrite ores in schistose or sheared rock, and associated with igneous intrusions; the minerals pyrite, chalcopyrite, sphalerite, galena, quartz, usually barite, and commonly a little arsenopyrite; an absence of high temperature minerals; scarcity of gangue minerals; presence of gold and silver; frequency of small amounts of less common metals such as bismuth, selenium and antimony; lens-like form; the association of sericitized rocks; original deep burial; and relatively old age. Further, the minerals bornite or pyrrhotite are scarce or absent, and in all of them pyrite is the earliest formed mineral. Segregations of richer chalcopyrite ore within the pyrite are common. To each one of these deposits a replacement origin has been ascribed by separate investigators working independently.

It is my conclusion, then, that the Huelva deposits gained their position by replacement of porphyry and slate through the agency of hot solutions. As to the source of the solutions, definite information is lacking. Unquestionably they were derived from a magma, and I agree with the conclusions expressed by Finlayson and Collins that they emanated from the same magmatic reservoir that gave rise to the whole series of allied intrusions in the district.

SUMMARY.

1. The Sierra Morena Mountains of southern Spain, in which lie the Rio Tinto and other deposits of the Huelva district, are mature mountains of erosion recently carved from a peneplain. The long-continued erosion that produced the peneplain, and to a less extent the post-peneplain erosion, not only brought the ore-

[115] Lindgren, W., "Geology and Ore Deposits of the Bradshaw Mountain District, Arizona," U. S. Geol. Surv. Bull. 782, 1926.

[116] Capps, S. R. and Johnson, B. L., U. S. Geol. Bull. 605, pp. 87–92.

[117] Watanabe, M., ECON. GEOL., vol. 18, pp. 174–178, 1923.

[118] Sagawa, Y., *Bull. Geol. Soc. Jap.*, vol. 22, p. 1.

[119] Watanabe and Landwehr, ECON. GEOL., vol. 19, pp. 434–454, 1924.

bodies to the surface, but offered favorable opportunity for oxidation and enrichment to take place.

2. The rocks of the vicinity consist of Culm (Lower Carboniferous) slates intruded by porphyries and diabase. The slates were involved in the Lower Carboniferous-Permian folding and now dip steeply northward. The intrusions took place toward the latter part of the folding, parallel to the slate bands, and are themselves slightly sheared.

3. The ore deposits, of which there are many, lie in slate or porphyry or at the slate-porphyry or slate-diabase contacts. Their loci were determined by structural lines of weakness, *i.e.* shear zones. Several pass from slate into underlying porphyry. They are elongated parallel with the structural lines and are in the form of great lenses arranged *en echelon*.

4. The deposits range in size up to a maximum of 1,700 meters in length and 250 meters in width. The maximum depth of known ore is nearly 550 meters.

5. The orebodies consist of masses of nearly pure sulphide flanked usually by disseminated sulphides, and inclosed within an aureole of highly sericitized rocks.

6. The ore is chiefly pyrite, with minor amounts of other sulphides, and from it is won copper and sulphur, with subordinate lead, silver, and gold. The ore is mined as smelting ore with around 2½ per cent. copper; leaching ore with 0.5 to 2 per cent. Cu, and 30 to 50 per cent. S; cupriferous sulphur ore with up to 2 per cent. Cu. and 55 per cent. S; and sulphur ore with low copper.

7. The minerals recognized are pyrite, chalcopyrite, sphalerite, galena, arsenopyrite, chalcocite, covellite, cuprite, goethite, hematite, tetrahedrite, enargite, luzonite, famatinite, chalcostibite, whitneyite, umangite (?), ullmanite, hauchecornite, and perhaps berthierite. Three unidentifiable minerals were observed. These heretofore unrecognized rare minerals account for the presence of silver, bismuth, nickel, cobalt, antimony, and selenium in the ore.

8. The supergene enrichment is small in degree but important

economically, and is of the usual type, consisting of replacement of primary sulphides by secondary chalcocite and covellite. The writer does not agree with the conclusions of Finlayson, Vogt, and others, that chalcopyrite, sphalerite, galena, and tetrahedrite are secondary (supergene) minerals.

The gossans consist of goethite. The transported "gossans" are hematite and goethite. The latter were formed on the old erosion surface and later were cut by stream erosion and left as isolated cappings on hills. Interesting problems connected with the gossans still await study.

9. The problem of origin of these deposits has been controversial. Originally considered sedimentary, they were next though to have been formed by hot solutions. A replacement origin was then suggested, but others thought that they were igneous magmatic deposits. At the International Geologic Congress at Madrid, an injected igneous magmatic origin was most favored.

It is the writer's conclusion that they are normal hydrothermal replacement deposits, having been formed by aqueous solutions that arose from the magmatic reservoir that yielded the intrusives, and followed shear zones, replacing the adjacent porphyry and slate with sulphides.

10. The deposits exhibit features common to those of Mount Lyell, Tasmania; Rammelsberg, Germany; Shasta County, California; Kyshtim, Russia; Tyee, British Columbia; Flin Flon and Mandy, Manitoba; Eustis Mine, Quebec; United Verde, Arizona; Ellamar, Alaska; Besshi and Hitachi Mines, Japan. All are lens-like pyritic bodies in sheared rocks, were deeply buried, contain similar minerals, have no high temperature minerals, have sericitized inclosing rocks, and have been ascribed a replacement origin.

The writer wishes to acknowledge with grateful appreciation the courtesy of the mine officials in the Huelva district and of the Spanish geologists of the International Geologic Congress. His

thanks are due to Messrs. Short, Agar, and Selchow for help received in minerals tests. He is appreciatively conscious of the value of discussions with his fellow members of the Congress in Spain, notably Messrs. Alvarado, Kemp, Ferguson, Singewald and Hewett, and he wishes to thank particularly Prof. Adolph Knopf, Dr. H. G. Ferguson, and Dr. D. F. Hewett, who have been kind enough to read and criticize this manuscript.

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BAUXITE DEPOSITS OF THE SOUTHERN STATES.

GEO. I. ADAMS.

It is here shown that the bauxite deposits of the southern states were formed under peculiar physiographic and climatic conditions and are all of approximately the same age. These conclusions, together with the statements concerning the occurrence and distribution of the known deposits, have a direct bearing on further prospecting and possible future developments.

Bauxite has been mined in the southern part of the Appalachian province and in the Coastal Plains. The deposits in the former region are related to a definite physiographic stage of development and were formed contemporaneously with those of the Coastal Plains which are associated with Eocene sediments.

Bauxite in the Appalachian Region.—It is generally accepted that the Appalachian region at the end of the Cretaceous was largely reduced to a base level which is known as the Cumberland base level, now represented in part by the surface of the Cumberland Plateau. In the Eocene the Appalachians stood higher and erosion established the Highland Rim base level. At that time in what is now the Appalachian Valley, there flowed a stream that has been called the Appalachian river, with a course that corresponded in a general way with the present Tennessee river in Tennessee and the Coosa river in Alabama. The remnants of its base level may be recognized along its former course by the concordant summits of the intermediate ridges which correspond to the Highland Rim peneplane. This base level was also established in the anticlinal valleys of northern Alabama, as for example, along Wills Creek, which is a tributary of the present Coosa river. It was at this stage in the development of the region that the bauxite deposits were formed.[1]

[1] Hayes, C. W., "Physiography of the Chattanooga District, in Tennessee, Georgia and Alabama." U. S. Geol. Surv., Nineteenth Annual Report, 1897–98.

The course of the Tennessee river from Chattanooga southwestward through the Cumberland Plateau is in a relatively young gorge that was not developed until Eocene time when, through piracy, the upper part of the Appalachian river was diverted across northern Alabama. Since that episode, the lower part of the Appalachian river has developed as the Coosa river. Both the Tennessee and the Coosa exhibit a lower stage of erosion, the development of which has partly destroyed some of the bauxite deposits and probably removed others.

The stream in northern Alabama which captured the upper waters of the Appalachian river, presumably flowed at that time on the Highland Rim peneplane. There are no intermediate ridges in the valley of the Tennessee river in northwestern Alabama because the structure does not favor their development, but there are physiographic features which correspond to that base level and some bauxite was formed there.

The accompanying diagrammatic cross section (Fig. 1) indicates the base levels enumerated above and shows the intermediate ridges in the Appalachian Valley. Most of the bauxite deposits of the Appalachian region occur on these intermediate ridges. The others, with the exception of some which are at higher altitudes, but were formed at the same time, are found in the anticlinal valleys in the Cumberland Plateau or in northwestern Alabama near the Tennessee river.

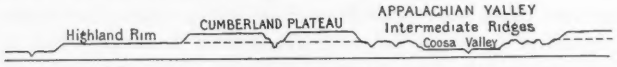

FIG. 1.

The bauxite deposits in the Appalachian region are in the form of " pockets " rather than " blankets " as is shown by the old pits.[2]

(See also, Vol. I, Geology, Chamberlin and Salisbury, Advanced Course, p. 160 et seq.) Johnson, D. W., Tertiary History of the Tennessee River. *Jour. of Geol.*, vol. 13, p. 194, 1905. (This article opposes the theory of an Appalachian river that was pirated by the Tennessee river. However the drainage may be interpreted, the physiographic relations of the bauxite remain the same.)

[2] Watson, Thomas L., A Preliminary Report on the Bauxite Deposits of Georgia. Geol. Surv. of Georgia, Bull. 11.

They are on areas of Paleozoic dolomite and limestone which have been subjected to deep weathering. In some of the deposits lignite is associated with the bauxite. For this type of deposits,

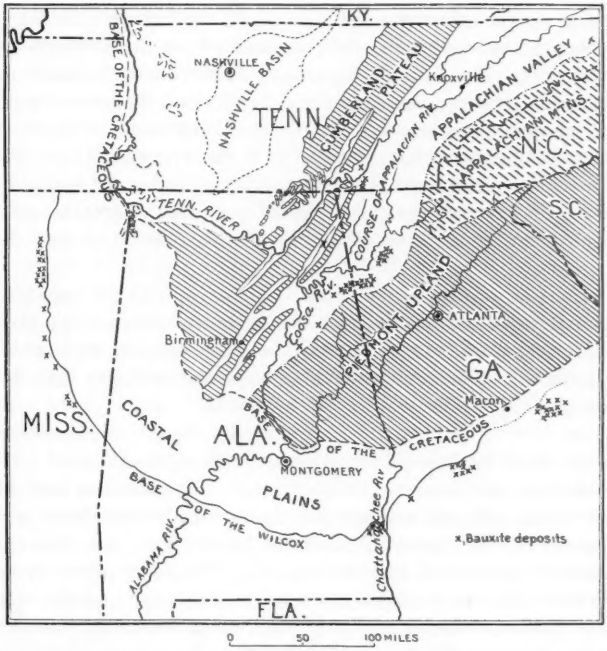

FIG. 2. Bauxite Deposits of the Southern Appalachians and adjacent Coastal Plains. By Geo. I. Adams.

found in pockets, the writer has suggested an origin in sink-holes.[3]

On the accompanying map (Fig. 2) the general localities of the occurrences of bauxite deposits are indicated by crosses. In the Appalachian Valley, bauxite has been found 200 miles northeast of Chattanooga, at an elevation of 2,200 to 2,300 feet, near

[3] Adams, Geo. I., "Formation of Bauxite in Sink-holes," ECON. GEOL., vol. 18, June–July, 1923.

Keensburg, Tennessee, and beyond the limits of the map, bauxite has been reported in southwestern Virginia in Botetourt county. At these localities, according to descriptions, the deposits have the form of pockets. There is no information which precludes their being assigned the same age as those on the intermediate ridges, although they are above the peneplane of which the ridges are remnants. The bauxite deposits in northwestern Alabama are found in pockets along Bear Creek, well above the present grade of the stream and below the base of the Cretaceous.[4] They occur in the Paleozoic formations and it is the writer's opinion after having examined some of them, that they were formed during the early Eocene physiographic stage of the valley and therefore at the same time as those of the Appalachian region already discussed.

Bauxite in the Coastal Plains.—These deposits are associated with Eocene sediments. Most of them are spoken of by those who have worked them as "blanket" deposits, but some are in "pockets." The correlation here presented indicates that they are all at approximately the same horizon.

In Mississippi, bauxite occurs in the Ackerman formation, which is at the base of the Wilcox group of the Eocene.[5] The Ackerman was deposited in fresh water. The adjacent land was low-lying, and peat swamps and shallow fresh-water lakes were common. The formation contains lignite beds, and iron carbonate is associated with the bauxite. The fossil plants of the Wilcox indicate a coastal flora of a decidedly tropical type.[6] They afford evidence of the climatic conditions that, combined with physiographic development, seem to have been requisite to the formation of the bauxite.

The Ackerman formation has not been mapped as such in

[4] Jones, Walter B., "Bauxites in Alabama, with a Special Discussion of the Margerum District," ECON. GEOL., vol. 21, Dec., 1926.

[5] Burchard, Ernest F., Bauxite in Northeastern Mississippi. U. S. Geol. Surv., Bull. 750 G, 1925. Morse, Paul Franklin, "The Bauxite Deposits of Mississippi," Miss. State Geol. Surv., Bull. 19, 1923. (This contains a summary of the literature on bauxite and affords many references.)

[6] Berry, E. W., "The Lower Eocene Flora of Southeastern North America." U. S. Geol. Surv. Prof. Paper 91, p. 137.

western Alabama. The equivalent there is probably the basal part of the Nanafalia which contains lignite beds. This formation needs some revision, since it is now made to embrace both marine and continental deposits. No bauxite has thus far been reported from western Alabama, but in Barbour county, at the eastern border of the state, bauxite deposits are now being worked from clay lenses in the "supposed Naheola" and at localities mapped as Nanafalia on the new geologic map of Alabama. Some of the bauxite has been described as lying in pockets in the Clayton limestone, which in that locality underlies the Nanafalia, and it has been suggested that such occurrences are in sink-holes.[7] The contact of the Nanafalia with the Clayton near Ft. Gaines has been described as showing ancient sink-holes, and such conditions are in accord with those favorable to the formation of bauxite.

In the Coastal Plains of western Georgia, bauxite has been mined from deposits which may be referred to the Wilcox since, although they have been mapped as Midway, the possibility that they belong to the Wilcox has been admitted.[8] These deposits are bedded and associated with clays.

In central Georgia there are bauxite deposits that lie in areas mapped as Cretaceous. The localities are separated from those just mentioned by an interval in which the Midway and Wilcox are cut out by overlap and the Ocalla is mapped in contact with the Cretaceous.[9] It is reasonable to entertain the idea that these deposits, which are in strike with the Eocene, are outliers of the Wilcox exposed along stream valleys where the Ocalla has been removed by recent erosion, which in some places has uncovered the Wilcox and in others has exposed the Cretaceous. This should be investigated, but the writer has been unable to undertake the study and it does not promise to be an easy matter to settle

[7] Rettger, R. E., The Bauxite Deposits of Southeastern Alabama. Econ. Geol., vol. 22, No. 7, pp. 671–672, Nov., 1925. Cooke, W., Geol. Surv. of Ala., Spec. Rept. No. 14, p. 257.

[8] Sherer, H. K., The Bauxite Deposits of the Coastal Plains. Geol. Surv. of Georgia, Bull. No. 13, pp. 64–65, 1917.

[9] See map opposite p. 134, in Bull. 40, Geol. Surv. of Georgia.

the age of the deposits since, in so far as present information indicates, invertebrate fossils are lacking.

If the occurrences in central Georgia are of Wilcox age, all the bauxite deposits thus far discovered in the Coastal Plains of Mississippi, Alabama and Georgia are at the same general horizon, and it is consistent to conclude that their origin, as well as the origin of those in the Appalachian region, was dependent on physiographic and climatic conditions which prevailed in the Eocene during the deposition of the Wilcox.

The bauxite deposits of Arkansas have been shown to be due to the weathering of syenite.[10] Some of them were formed *in situ* and others, removed from their place of origin, are interstratified with Tertiary sediments. The age of the bauxite-bearing sediments has not been closely determined. It is possible that it is the same as of those in Mississippi, Alabama and Georgia, and that they had their origin under the same climatic and similar physiographic conditions. In this connection it is interesting to note that the diaspore clays of Missouri, which occur in what appear to be ancient sink-holes, lie inland from the Arkansas bauxites in relations somewhat analogous to those which exist between the bauxites of the Appalachian region and those of the Coastal Plains.

The emphasis here placed on the climatic and physiographic conditions which prevailed during the origin of the bauxite deposits of the southern states is in accord with much which has been written concerning the occurrences of bauxite within the tropics in regions of abundant rainfall and on low-lying coasts or lands which had reached an advanced stage of topographic development.

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[10] Mead, W. J., "Occurrences and Origin of the Bauxite Deposits of Arkansas," ECON. GEOL., vol. 10, pp. 28–54, 1915.

IGNEOUS DIKES IN BANDERA COUNTY, TEXAS.[1]

J. M. DAWSON, MARCUS HANNA, AND GRADY KIRBY.

INTRODUCTION.

SINCE oil was found in serpentine at Thrall, Williamson County and at Lytton Springs, Caldwell County, Texas, considerable attention has been directed toward the search for other igneous masses in Southwest Texas in the hope of finding more oil. Tate [2] reported the occurrence of a trap-rock dike on the Batto farm about one mile northwest of Bandera on the west bank of the Medina River in 1888. The writers have found another occurrence of igneous material in Bandera County, which is associated with faulting, as well as extending the known length of the dike noted by Tate. Numerous igneous masses have been described or are known to exist along the Balcones zone of faulting as far north as Williamson County. However, on the Edwards Plateau the dike near Bandera is thought to be the northwesternmost igneous mass south of the Central Mineral Region.

LOCATION AND GEOLOGY.

The easternmost exposure of the dike referred to by Tate [3] is in the Hendricks Arnold Survey 53 on the Batto farm and will be referred to hereafter as the Batto Dike. It is found at intervals for a distance of four and one half miles striking in a direction of south eighty degrees west and terminates, as far as could be determined, in the Francis Winans Survey 46. It can be traced continuously for a distance of forty-five hundred feet on the west end. If it extends beyond these limits it is buried by surface materials.

[1] Published with permission of the Gulf Production Company. Presented before 12th Annual Convention, Amer. Assoc. of Petroleum Geologists, Tulsa, Okla., March, 1927.

[2] Tate, J. L., Texas Geol. Surv. Report of Progress No. 1, pp. 64–69, 1888.

[3] Tate, *op. cit.*

This dike, as does the second exposure of igneous material mentioned below, occurs in the physiographic province of the Edwards Plateau. The country rock belongs to the Glenrose

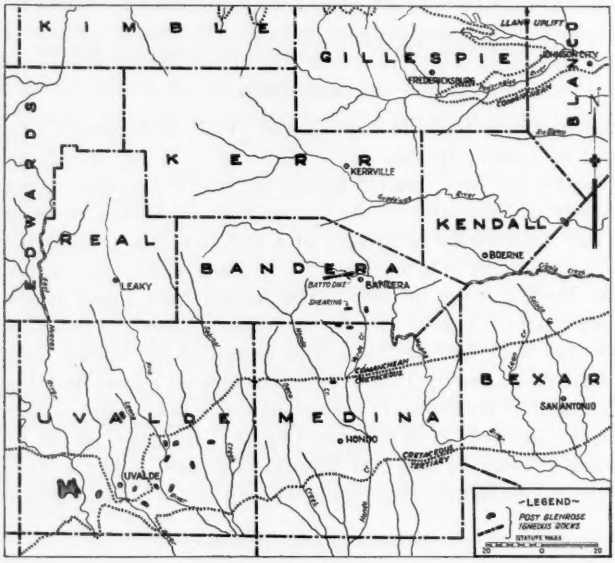

FIG. 1. Map showing the location of a part of the post-Glenrose igneous rocks of the Central Texas Region,[4] including those of Bandera County.

formation of Comanchean age, with *Orbitulina Texana* Roemer, and consists of yellowish, argillaceous limestones and fossiliferous marls; the whole weathered and eroded to form the bench-like topography characteristic of the Glenrose formation. The regional dip is not more than thirty feet per mile to the southeast, and is apparently not distributed by the dike.

[4] Igneous rocks, other than those of Bandera County are after: Udden, J. A., Geological Map of Texas (rev. ed., 1919) published by the Bureau of Econ. Geol. and Tech., Univ. of Texas, 1919; and Liddle, R. A., "The Geology and Mineral Resources of Medina County," Univ. Texas Bull. 1860, 1918.

The average width of the Batto Dike is probably about four feet, although it varies from two to six feet. At the locality on the west bank of the Medina River on the Batto farm a pit was excavated many years ago to a depth of eight feet. The trap-rock [5] at this point is only partly altered to serpentine and other alteration products. The walls of the pit are nearly vertical and disclose a zone of recrystallization some eight or ten inches in width, most pronounced at the contact with the igneous material. Even in the most recrystallized portions of the walls no evidence of pneumatolytic action was found in thin sections. Four chemical analyses were made of the country rock, two at the contact, and two from a foot away. One of each was from the east and one of each from the west end of the dike. In all four of these the calcium carbonate content was nearly one hundred per cent. Not more than a trace of magnesium was found, although the magnesium content of the Glenrose rocks at certain points indicates dolomite rather than limestone. The writers are of the opinion that the magma was dry and rather cool when injected.

Along the strike of the dike to the west, after the dike leaves the river and goes to higher ground, its trace becomes very prominent. The igneous material is completely altered to soft serpentinic material, which has eroded to a long, shallow, narrow depression. On either side of this depression the recrystallized walls stand out prominently, at times rising several inches above the general level of the surrounding surface. Beyond the immediate walls the country rock is much softer, and more easily eroded, although somewhat more resistant to erosion than the weathered altered igneous material of the dike.

The second exposure of igneous material noted by the writers in Bandera County is located in the northeastern corner of the Joseph Dial Survey, some five and one half miles south of the town of Bandera on the Bandera-Hondo road. At this exposure the structure could not be determined. The material consists of

[5] Since Dr. J. T. Lonsdale, of the Bureau of Economic Geology and Technology at Austin, Texas, is preparing a bulletin concerning the post-Glenrose igneous rocks of the Central Texas Region, a detailed description of this trap-rock will be left to him.

completely altered trap-rock, the original character of which has not been determined because of its altered and weathered condition. Included in the altered igneous material are chunks of finely recrystallized limestone, which, however, still show the original outlines of included fossils. Boulders as much as five inches in diameter were noted. A few of the boulders have been fractured and the fractured parts recemented with calcite. The country rock about this exposure shows dips as high as sixteen degrees in a direction away from the exposure. The exposure here is not of large size, consequently it could not be determined if the dips are on a quaquaversal structure or not.

Almost due west of this second exposure were found well developed gouge zones which trend nearly east and west. On two of these oil prospecting has been carried on and is now under way. One pit on the Saathoff farm was sunk to a depth of seventy feet, but was abandoned because of water trouble. Another pit has recently been sunk to a depth of fifteen feet, and is still being deepened. The walls of the pit are nearly vertical with no deformation of the walls. The trace of the gouge zones can be followed fairly easily on the surface. No associated igneous material was found, but the general east-west trace being parallel to the trace of the Batto Dike, and the location of the second exposure of igneous material leads us to believe that there may be some relationship between the dike, the second exposure of igneous material, and the gouge zones.

EDITORIAL

A NEEDED LINE OF RESEARCH.

THE field of economic geology may commonly be regarded as divisible into two parts—the metallic and non-metallic. The former is so well treated in journals and magazines devoted to the applied side of geology that most geologists who are interested in the economic phases of their science are somewhat familiar with its problems, and the same is probably true of coal, oil and gas on the non-metallic side.

In the case of the other non-metallics, however, there is sometimes a rather wide spread unfamiliarity with the characters and problems of not a few of them, including some that are by no means unimportant. What is still more regrettable is that this unfamiliarity is occasionally reflected in erroneous statements appearing in reports and even text books.

In this day of specialization, it is difficult for the general geologist to keep in touch with the varied problems of the non-metallic field, the more so, because some non-metallics are dealt with chiefly in special magazines, thus enlarging the list of publications that the geologist wants to keep track of, but does not always succeed in doing.

Possibly no better material can be used to illustrate our point than common clay, a mineral product so abundant that many, no doubt, believe there is little still to be found out about it. However, while it is true that much work has been done on it, considerable still remains to be done.

If one can judge from the positive statements that appear from time to time in books, the constitution of clay appears to be definitely known, for we still read that all clay is a hydrous silicate of alumina, that kaolinite is its most important constituent, and likewise the cause of its plasticity. These are all ideas which

it can be seen were exploded 20 years ago, if any one takes the trouble to look up the literature.

But while we know that clay is much more complex mineralogically than intimated above, and that kaolinite (not kaolin as many persist in calling it) is not its chief constituent, nor even the actual cause of its plasticity, there is still a vast lot to be learned about it.

A perusal of some works leads us to believe that much is known regarding the mineralogy of clays, for Howe in his Handbook of Kaolin, lists about 60 so-called clay minerals, all hydrous aluminum silicates, and Wherry has added still others to the lot.

The descriptions of many of these have been based on chemical analyses, and in part on physical properties, but there must be a strong suspicion in our minds that all these are not good species nor are they all common constituents of clays. And so right in this field lies an excellent opportunity for research; but it will not lead anywhere unless the right path is followed.

For a long time chemical analysis alone was a favorite means of solution, and much energy has been wasted in attempting to figure out the mineralogical composition of a clay from its ultimate analysis. It may work for igneous rocks, but it will not do for clay, since we are not dealing with a crystalline mass, but a mixture of crystalline grains, colloids and adsorbed compounds.

The rational analysis, formerly much used by the Germans for determining the percentage of clay substance (supposed to be kaolinite), quartz and feldspar, was thought to be a step in the right direction, but this method has been practically abandoned, since it has been discovered that even white clays are not always as simple mineralogically as they were thought to be, and also because we have found that our knowledge regarding the solubility of the clay minerals is inaccurate.

The weakness of chemical analyses as a means of calculating the mineralogical composition is well brought out by comparing the mineral composition of a clay as figured from the ultimate and rational analyses. More unlike results could hardly be imagined.

The dehydration curve has also been used as a means of mineralogic identification, because of the well known fact that many of the hydrous aluminum silicates, and aluminum hydroxides (which may be present in some clays) lose their chemically combined water at more or less definite temperatures, or within certain temperature ranges. Le Chatelier tried this method years ago, and more recently J. W. Mellor has attempted its use to prove the presence in clays of a mineral which he termed *clayite*. There seems no doubt that this line of attack is somewhat uncertain unless it can be proved that the material studied is mineralogically homogeneous.

Having discarded everything thus far, the only apparently safe means of study left appears to be the petrographic one, even though we must realize that clay may contain particles of ultramicroscopic size.

However, the work which has been done by Wherry, Somers, Ross, Shannon, McCaughey and others, leads one to feel that the petrography of clays offers a great field for intensive research, and in fact along two lines, viz. (1) A study of the raw clays, to clear up the constitution of these plastic materials, and (2) An investigation of the fired ones, to show the effect of rising and elevated temperatures on the changes in optical properties of the constituent minerals, the development of new ones, and the reactions which may take place between the grains.

Some of the results already obtained might be mentioned, to indicate the importance of the petrographic method. Kaolinite, still referred to by many as the "basis of all clays" is found to be far from abundant in some, hydromicas often greatly exceeding it in amount. Sericite seems to appear as an intermediate product in the alteration of feldspar to kaolinite, and the question is whether it often plays this rôle. The curious white clay, Indianaite, from Huron County, Indiana, listed by Dana as a variety of kaolinite, breaks down under the microscope into several minerals, kaolinite, sericite, etc. It is a rock, not a mineral. The microscope also has done much to clarify our ideas regarding that peculiar clay called bentonite.

And while we have this problem before us, let us not forget that there are others to be solved, among them the origin of the clay minerals. Are they always the result of low temperature conditions formed either by weathering or rising tepid solutions, or may they not in some cases be the work of hot waters? The advocates of these two views seem rather unyielding at present, but when all the evidence for both sides is carefully considered, perhaps each may be willing to admit that there may be an element of reason in the other's theory.

With the beginning that has been made, the work should be continued until the whole line of hydrous aluminum silicates has been overhauled.

H. RIES.

DISCUSSION AND INFORMAL COMMUNICATIONS

TWO KINDS OF MAGNETITE?

Sir: In the fall of 1926 the junior writer found a brownish magnetic mineral which replaced bluish magnetite in a suite of ore specimens from Meme, Terre Neuve, Haiti. This mineral which in polished sections is brownish by comparison with the adjacent bluish magnetite has since been found in ore from a number of other localities. Apparently the same mineral has been produced by oxidizing polished sections of bluish magnetite in the oxidizing flame of a blow torch at a very low red heat. Also it has been produced from fragments of bluish magnetite in a furnace with an oxygen atmosphere at about the same temperature. If a higher temperature is used, hematite forms.

The properties of this brownish magnetite (?) are as follows: It is brownish by comparison with the bluish magnetite which it replaces, but the difference is so slight that unless both minerals are in the field it is hard to determine which one is present. It varies somewhat in intensity of color. The hardness is slightly less than that of the bluish magnetite. It is isotropic in polished section under polarized light like the bluish magnetite. Tiny fragments which appear homogeneous under high magnification jump to a horseshoe magnet. All these features pertain to both the natural and the artificial examples so the presumption is strong that they are the same thing.

Several recent papers [1] call attention to the laboratory production of oxidized magnetite and the possibility of its being found in nature. In fact an example has been described by Sosman and

[1] Sosman, Robert B., and Posnjak, E.: "Ferromagnetic Ferric Oxide, Artificial and Natural," *Jour. Wash. Acad. Sci.*, vol. 15, pp. 329–342, 1925.

Twenhofel, L. H.: "Changes in the Oxidation of Iron in Magnetite," ECON. GEOL., vol. 22, pp. 180–188, 1927.

Posnjak from Iron Mountain, Shasta County, California. Since the present writers think that the brownish mineral found replacing the bluish magnetite is oxidized magnetite similar to that produced experimentally, it was thought that a short description of the occurrences in nature might be of interest.

Ore from Terre Neuve, Haiti, shows bladed hematite crystals sometimes partly and sometimes wholly replaced by bluish magnetite. Brownish magnetite replaces the bluish variety and forms a border zone of varying width around the former hematite crystal. This zone is clearly one of replacement, for veinlets project from it both irregularly and along octahedral planes into the bluish mineral and residuals of the host occur in the invading one near the general boundary of the two. These residuals are frequently dissected along octahedral planes resulting in scattered fragments all showing the same orientation. Some sulphides are present later than the hematite but their age relation to the brown magnetite could not be determined.

One specimen from the Richards Mine, near Dover, N. J., has the usual massive bluish magnetite of this district in part replaced by the brownish variety. The replacement has proceeded in preference along magnetite grain and gangue mineral boundaries. From these vantage surfaces the replacement advances into the magnetite chiefly along octahedral directions of the host.

The brownish replacement variety is widespread in the magnetite ore of Cornwall, Pennsylvania. Bluish magnetite is the greatly predominant ore mineral of this place, but the brownish variety is found in nearly every section examined. A comprehensive suite of specimens collected by W. H. Callahan shows the accessory magnetite in the diabase sheets at this place is bluish magnetite also partly replaced by the brown variety. In both the ore and the diabase the replacement has been around the outside of the host crystal. The usual cross-cutting and irregular veinlets are present as well as the pronounced relation to the octahedral directions of the host.

Juragua, Cuba, magnetite is chiefly bluish, but several sections

show the brownish mineral present to the extent of several per cent. of the ore. In the sections showing both varieties rounded anhedrons of bluish magnetite have a thin line of hematite bordering the crystals. Brownish magnetite is present in many crystals as a highly irregular zone between the hematite line and the core of the bluish magnetite. The relation of brown to blue is that of replacement but not so well displayed as in the other examples described.

Both brownish and bluish varieties are present with other minerals in a suite of specimens from White Horse, Yukon. The peripheral replacement of bluish magnetite by the brownish variety and the control of replacement by octahedral directions of the host is pronounced. Over a fourth of the magnetite in the sections examined proved to be the brownish variety.

Sections of nickel ore from the Copper Cliff Mine, Sudbury, and of cobalt-nickel-silver ore from Gowgonda, Ontario, show small isolated bluish crystals of magnetite which have been replaced peripherally by brownish magnetite, resulting in a narrow irregular zone surrounding the unchanged bluish core. Veinlets of the brown project into the bluish mineral and control of replacement by octahedral directions of the host is marked.

Certain other features have been noticed which may or may not have a bearing on this question. Some sections of magnetite from Cranberry, N. C., Tillie Foster Mine, N. Y., and one from Port Henry, N. Y., have large brownish magnetite crystals intermingled with large bluish ones. The common magnetite at Port Henry, N. Y., and the Tillie Foster Mine, N. Y., is the bluish variety. The color difference is not as strong as where the brownish mineral replaces the other. The cause of color difference may not be the same in the two types. It may be due to a difference in original composition and not brought about by later processes. It is noteworthy that all the bluish magnetites tested show traces of titanium.

The Swedish magnetites in general have a pronounced reddish cast to the brown in polished section. This reddish cast is noticeable when the mineral is in contact with specularite or bluish mag-

netite. Localities producing this reddish magnetite are, Tuollavara, Norberg, Striberg, Grangesberg, and the Strossa district, all in Sweden.

In brief, the tentative idea is advanced that the brownish magnetite replaces the bluish one because it is an oxidation product of the later. Unfortunately no material of this type suitable for analysis has been found. The oxidatized magnetite made by Sosman and Posnjak has a brownish color and is magnetic. In these features it agrees with the natural mineral just described. The artificial oxidized product of magnetite made by the writers has apparently the same properties in polished section as the natural brownish mineral which replaces bluish magnetite.

As to the temperature and time at which oxidation took place little can be said. The occurrence at Cornwall, Pennsylvania, suggests its formation there by hypogene solutions.

The writers wish to express their thanks to Professor Lindgren, who gave helpful discussion and encouragement throughout the work.

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THE PHOSPHATE DEPOSIT ON OCEAN ISLAND.

Sir: Having recently returned to England after a long absence abroad, I have had the opportunity of reading "Phosphate Deposits of the Pacific" presented by Mr. Danvers Power, in the May, 1925, issue of ECONOMIC GEOLOGY.

As Mr. Power criticizes certain of my views as to the mode of formation of the phosphate deposit on Ocean Island, I believe it is desirable to reiterate the very important evidence which he ignores and to correct a misquotation and misinterpretation of my work.

In his article (p. 278), Mr. Power again brings forward the idea of the enrichment of tribasic phosphate, in a mixture of calcite, aragonite, dolomite and phosphate, by differential marine

denudation. He states that: "Carbonate of lime, whether in the form of aragonite or calcite, being less tough and more soluble than the tribasic phosphate, would be broken and dissolved, setting free the phosphate which would collect in the gulleys together with some coral sand."

Now, calcite has a hardness of 3 in Moh's scale, aragonite 3.5–4.0 and dolomite 3.5–4.0, while the general run of Ocean Island phosphate is from 2 to 3, although exceptional specimens attain a hardness up to 5. Further, the general tendency of marine action, as observed under the conditions prevalent on Ocean Island is to increase the proportion of calcium carbonate in a phosphatic gangue, and not to decrease it.

To quote at length from my paper:[1]

> "First, the dolomite, in the cavities of which Mr. Danvers Power's 'primary rock-phosphate' occurs, is much harder than the general mass of the phosphate. Even if it were not so, the complete absence of unphosphatized coral fragments within the deposit would be difficult to explain. Secondly, the theory in no way explains the observed uniform variation in the percentage of tricalcium phosphate, according to the position of the sample taken. Thirdly, on the southern coast, where the phosphate reaches sea-level, the very action which Mr. Power regards as having produced a material containing 80 per cent. and more of tricalcium phosphate is in actual operation at the present day, and the result is a coral-sand containing usually less than 5 per cent. of tricalcium phosphate. Lastly, what Mr. Power considers to be waterworn grains are really pisolitic and oolitic particles, exhibiting, under the microscope, an internal banded structure, the bands being conformable with the outlines of the grain."

As to the occurrence of "water-worn boulders of phosphate sandstone on the top of the islands," I may remark that their occurrence is general throughout the deposit, wherever detrital limestone might be expected to occur in the reef, previous to the deposition of the guano. Further, the composition of such boulders follows, in general, the rule that is given in my paper and it has always appeared to me more logical to regard them as not differing in origin from the surrounding deposit, which imitates the other forms of detrital limestone.

[1] "The Phosphate Deposit of Ocean Island," *Quart. Jour. Geol. Soc.*, vol. LXXIX., Pt. 1, p. 11, 1923.

In any case, the point has no bearing on the validity of my theory, as such "water-worn boulders of phosphate" could have been formed when the present highest point of the island was at sea level, *i.e.*, in the initial stages of the deposition of the guano.

What I do insist upon is that the available evidence demands that no extensive submergence has occurred since the deposition of the guano.

Mr. Power misquotes me as stating "both depression and emergence appearing to have been regular and without sensible break." I wrote *deposition*, not depression, which rather alters the sense of things and the validity of Mr. Power's criticism.

The three tilted platforms which can be traced around the island are, of course, the product of marine denudation, during breaks in the movement of the island, previous to the deposition of the guano.

Now as to dolomitization: At depth, the reef underlying Ocean Island, just as in the case of Funafuti, has a very variable Mg-content, the average being below 20 per cent. $MgCO_3$ in the few samples I took from the deeper inland caves. Immediately underlying the phosphate, however, for a thickness varying from a few inches to several feet, the coral consistently is almost completely dolomitized (43–45 per cent. $MgCO_3$). As fresh guano often contains 2 per cent. of $MgCO_3$, while the percentage in Ocean Island phosphate is usually too small for determination and very rarely exceeds 0.5, it is logical to assume that this dolomitization is largely due to magnesium leached from the guano.

On p. 333 of your June-July, 1925 issue, Dr. William A. P. Graham, in his interesting work on the "Origin of Phosphate Deposits," suggests that my conclusions as to the genesis of translucent phosphates are at variance with his results. This, however, is not the case, as I conceive that translucent phosphate is deposited as a gel from colloidal, and not from true solution.

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REVIEWS

Leached Outcrops as Guides to Copper Ore. By AUGUSTUS LOCKE. vii + 175 pp., 18 figs., 24 plates. The Williams and Wilkins Company, Baltimore, U. S. A. 1926. Price $5.00.

The expressed purpose of this book is to help combat the steadily rising cost of finding ore. With this purpose all who have to do with this phase of mining will be in sympathy. For years we have heard much lamentation because of the passing of those picturesque partners in the mining industry of the earlier days the "prospector and his burro," and many reasons for their demise, and plans for bringing out another crop have been advanced.

Most mining men, however, clearly recognize that the old time prospector has disappeared because his methods produced a steadily decreasing number of promising prospects and mines and not because there is a lack of market for such if found.

The search for ore may be divided into three overlapping stages all of which are yet operative to some extent. The first stage was that of the prospector and practical miner. Their highday was when the country was first opened. Many ore bodies were to be found outcropping or plainly indicated on the surface and requiring but a few feet of digging to expose them. The metallurgy of the ores was relatively simple and, in some cases, one man possessed the technical skill needed to find, mine, and treat them. As these outcropping ores became scarce and mining extended deeper and into more complex ores, the practical miner found himself in trouble and the second period arrived, that of the mining engineer.

The engineer's problem was the extraction of the deeper ores with all its difficulties and the treatment of the increasingly complex ores. This continued until the ore bodies became exhausted, or too low in grade, or too refractory to be profitably exploited, when new deposits were sought. The operating engineers tried their hand at this search with varying success but gradually the more progressive operators realized that it was not a job that could be effectively carried out in odd moments between the other demands on the time of the operating engineer. A man was set to the particular business of finding ore, and we have the third stage, that of the mining geologist.

That the mining geologist has proved his usefulness is indicated by the steadily increasing demand for his services. At the beginning of the present century hardly a mining company employed a geologist as a part of its operating force. To-day hardly a large company, that has as one of its major problems the finding of more ore, is without one or more geologists regularly on its staff. Their labors are adding much to the knowledge of ore deposits.

The study of the outcrops of mineral veins has of course, been pursued as long as man has been interested in the recovery of the metals. The prospector was a close observer of mineral outcrops and his success depended on his ability to interpret what he saw. Rarely, however, did he put on record his observations, and each succeeding prospector had to start from the beginning and had little advantage over his predecessor. To this fact, largely, is due his passage from the field, if indeed, there has not been a gradual transition from the prospector of the past to the economic geologist of to-day.

There has grown up a very large literature on the subject of mineral and rock alteration. Few geological reports whether describing ore deposits or describing rocks in general, but have something to offer. The numerous monographs on ore deposits are, of course, especially prolific sources of observation. More general works that treat the subject, to mention only some of this country, are Van Hise's "Treatise on Metamorphism," Merrill's "Rocks, Rock Weathering and Soils," Clarke's "Geochemistry," Twenhofel's "Treatise on Sedimentation," and W. H. Emmon's "Bulletins on the Enrichment of Ore Deposits," not to enumerate the textbooks on general geology and mineral deposits. The subject has also been given attention by chemists notably by those of the U. S. Geological Survey and the Geophysical Laboratory.

The specific subject of mineral outcrops has been the subject of several papers, such as W. H. Emmon's "Outcrops of Ore Bodies," published in 1909, and F. H. Probert's "Surficial Indications of Cooper," published in 1916. Several papers have been published by Dr. Locke and those associated with him during the period in which the material for the present book was being accumulated. It is evident that the subject of outcrops of mineral veins is one that has long received consideration, but the work on which this book is based has been the most ambitious undertaking directed specifically to that purpose. Moreover Dr. Locke has been successful in enlisting the interest of chemists and mineralogists to coöperate with the geologist, which has added greatly to the value of this work, as it has to the study of secondary enrichment and also to the understanding of primary ore deposits, although in the latter field much yet remains for the chemist to do.

In the introductory chapter the author outlines the difficulties of the problem and recognizes the present limitations. The success of the method depends on ability to reconstruct the original minerals from the weathered product somewhat as another line of workers reconstruct the appearance of an ancient animal from a jaw bone or skull.

The less the change, the easier the reconstruction and hence the disseminated copper ores with a large amount of gangue and relatively small amount of sulphide are chosen as a starting point.

Some readers may feel that the previous literature is not adequately covered by the "selected bibliography" of some forty-five titles listed in Chapter II. Such criticism is probably inevitable in any "selected bibliography."

Chapter III takes up the method followed, beginning with sampling the metore or material remaining from the altered ore. Engineers will recognize that this is fundamental, as no interpretation can be more reliable than the sample from which it is made. It is pointed out that the surface does not give an instructive sample and that even sampling below the zone of surface accumulation must be done with caution and understanding. The discussion of the chemistry of oxidation of sulphides leads to the conclusion that the alteration of pyrite alone results in the removal of more of the iron than is removed in the alteration of copper-iron sulphides or of mixed pyrite and copper sulphides. Also that such oxidation as takes place below water level results in removal of more iron than in oxidation above water level. The difference between the oxidation under flooded conditions and where water is present only as films leads to differences in solution concentration and differences in the resulting minerals.

The gangue minerals associated with the sulphides also exert an important influence on the movement of iron. In general, gangue relatively inert to acid solutions like quartz favors movement of iron, while a gangue reactive to solutions like calcite favors precipitation of iron. Feldspar, kaolin and mica lie between the extremes.

The subject of cavities or voids is examined to develop criteria for determining the type of minerals removed, if indeed a mineral has been removed. The formation of large caves where massive bodies of sulphide have oxidized, with the slumping of the unsupported roofs, in some cases extending to the surface, is pointed out as a means for locating hidden ore bodies.

The presence of metals in non-sulphide form, as native metal, chloride, carbonate, sulphate, or silicate, gives some guide to the primary ore beneath. The retention of the metals in the outcrops is largely controlled by the original character of the ore especially the gangue minerals.

Gold is commonly retained, though leached under some conditions.

Silver, except where chlorine is present, behaves much like copper, being retained only where the gangue is readily reactive, as is true of zinc, also. Lead, on the other hand, ordinarily forms relatively insoluble oxidation products and commonly is to be found at or near the outcrop.

The author clearly recognizes that the finding of portions of the original sulphide preserved in the oxidized outcrop is the best evidence of the character of the ore body. A chapter is given to discussion of the reliance to be placed on remnants of sulphide. The most significant result of this analysis is to point out that pyrite is likely to survive longer than the other sulphides.

The next problem is the reconstruction of the original ore from the weathered products, with the aid of relict sulphide masses if possible, but without this aid if such must be.

The recognition of iron that has not moved during oxidation and iron that has been transported before being redeposited, is of prime importance. The reduction of the common oxidation products of iron to goethite, hematite, jarosite, siderite and nontronite is a decided step in advance in mineralogy. Many geologists have doubtless been surprised to find how much hematite has been formed in the capping of some disseminated deposits, and how much jarosite in others.

Perhaps the most important conclusion reached on this subject is that a high ratio of indigenous to transported iron means a high ratio of copper to iron in the original ore. The same is indicated in the mineralogy by a high ratio of hematite to goethite or of hematite plus goethite to jarosite. Abundant jarosite is believed to indicate abundant iron sulphide in the original ore. Color in capping and gossans is regarded as helpful in determining mineralogy but this must be used with caution and judgment.

The remaining chapters of the book are given to the application of the ideas developed to determine the meaning of outcrop. After giving a list of descriptive terms relating to iron oxides, a "limonite scale" is introduced based largely on the degree of transportation of the iron of the original minerals. This ranges from "relief limonite," and "limonite" pitch, in which the iron occupies essentially the position that it did in the original sulphides and is interpreted as representing veins with little or no pyrite, to halos and borders attached to voids and to "limonite" flooding the matrix and not definitely associated with its parent mineral, which are interpreted as representing alteration of pyrite.

It is impracticable to discuss each of the eight divisions in a brief review, but from the standpoint of application they are the meat of the nut and are deserving of most careful study. From the consideration of these types, the author gives examples of reconstruction of the original sulphide and estimation of the original copper content.

With the original sulphide from which the capping was derived, reconstructed in the imagination of the worker, the next problem is to estimate as well as may be the position, grade, and thickness of the enriched ore that is expected beneath, or in the direction in which the solution moves. This necessitates a consideration of structure, texture and mineral composition and, of course, is tested by some method of underground exploration which marks the stage when outcrop study gives place to or is combined with underground exploration.

The author has not minimized the difficulty of judging outcrops even in the simpler cases of disseminated copper deposits. Yet the reviewer cannot help but feel that the student geologist might easily get an erroneous conception of the ease and accuracy of such judgings.

It will be well to remember that one may know the rules of music or golf and yet without much and constant practice make a poor showing at playing an instrument or the game. This fact however, does not stay us from playing the fiddle or using the golf clubs, and it should only encourage the study of outcrops for those whose business is the search for ore. The reviewer recommends a most careful study of this book to all who are interested in the search for ore. It does not give and does not pretend to give infallible rules, that can be applied by anyone for judging mineral outcrops, but any geologist who carefully studies the book will see things in an outcrop that he has not seen before.

The reviewer feels that Dr. Locke has done a very real service to the science of ore deposits in bringing out this book on mineral outcrops. It is hoped that this volume represents but a beginning and that the study will be carried to the more difficult types of deposits by the author and others who are and may become interested.

The publishers have turned out a very pleasing volume. One cannot say more for this feature nor should he say less than that they have gone far toward realizing the motto of the Waverly Press "Without a flaw."

B. S. Butler.

U. S. Geological Survey,
Golden, Colo.

The Scientific Principles of Petroleum Technology. By Leo Gurwitsch, translated and revised by Harold Moore. 470 pp., with 13 diagrams and 8 plates. D. Van Nostrand Co., New York, 1927. Price, $8.00.

In the preface to the first edition of his work Professor Gurwitsch says that his aim was "to give a general view of the scientific side of the subject to the chemist interested in the petroleum industry. In consequence all practical questions of technology (such as methods of carrying out chemical processes, constructive details, etc.) have been entirely

left out of consideration." The book deals mainly with the theory of the various processes and reactions, and the methods for detecting them.

The first section of the work, comprising about one-half of the whole, deals with the raw material. Of this, Part A describes the chemical constituents of petroleum and their behavior with different reagents. Part B deals with the physical characteristics of crude oils, such as specific gravity, viscosity, surface tension and the optical, electric and thermal properties. Part C gives briefly the characteristics of the most important crude oils. However, no petroleum from Oklahoma is mentioned, and the Trenton-limestone pools of Ohio and Indiana are miscalled the "Mid-Continental Field." Part D, which deals with the chemical evidence as to the origin of oil, is perhaps the most interesting part of the book for the general reader. The conclusion is reached that the data are strongly in favor of an organic origin. The second section of the work deals with the preliminary treatment, distillation and refining of petroleum. The theory of steam distillation, vacuum distillation and cracking is discussed at some length. Considerable space is also devoted to the description of refining by sulphuric acid and caustic soda. The final section has to do with the various products of refining and with the explanation of their valuable properties.

WILLIAM L. RUSSELL.

Geology and Ore Deposits of the Ducktown Mining District. By W. H. EMMONS and F. B. LANEY. U. S. Geological Survey Prof. Paper 139, 1926. 43 Plates, 15 figs., 114 pp. Price 65 cts.

This long awaited publication follows fifteen years after a brief summary report in which Messrs. Emmons and Laney gave us the benefit of their ideas of the geology of the Ducktown district in 1911. Scattered references to the district have appeared from time to time in the writings of Professor Emmons, but this is the first comprehensive treatment of the geology and ore deposits. This district is of more than usual interest since it includes the largest and among the oldest copper mines of the East and lies in the heart of the Southern Appalachian structure.

The report is gotten up in the usual systematized and excellent form of the Survey Professional Papers. A wealth of well-reproduced illustrations tell the story of the district hand in hand with the text. But when I turned first to inspect the most important illustration, the geologic map of the quadrangle (in pocket), I found it strangely lacking in geology. It shows excellent topography but little else. Numerous colored lines in the center of the sheet denote, according to the legend, ore, dikes, staurolite schist beds, bluish-black schist, crinkled mica schist, gray mica schist, and conglomerate beds. As to what rocks underlie the main part

of the quadrangle the reader cannot tell, and the legend offers no clue. Presumably it is the Great Smoky formation, for the text states the rocks are almost wholly metamorphosed Lower Cambrian sediments of the great Smoky formation.

Chapters II. and III., 21 pages, by Dr. Laney, present first an excellent outline of the broader features of the Southern Appalachian geology, followed by detailed descriptions of the various schists of the Great Smoky formation in the district.

The major part of the book is devoted to ore deposits and descriptions of the mines by Professor Emmons. He believes that a thin discontinuous bed of limestone in what are now metamorphic rocks was changed during the metamorphism to a mass of complex silicates of which the most important are actinolite, tremolite, garnet, pyroxene, zoisite, quartz, and calcite, and that the ore minerals, pyrite, pyrrhotite, chalcopyrite, sphalerite and galena replaced the silicates at a slightly later date. Thus the loci of metallization were the limestone horizon. Subsequently the deposits were superficially altered and a thin blanket of high grade enriched copper ore was formed. The complex hypogene and supergene mineralogy receives much space. A feature of interest is the occurrence of skeleton crystals or crystallites of sphalerite in massive chalcopyrite. Some 29 hypogene and 27 supergene minerals are listed, and talc is included as a supergene mineral. More space is devoted to the small but interesting deposits of secondary enrichment than to the primary ore. We regret that these unusual primary deposits might not have been dealt with more fully.

Those who follow geology and mining will find much of interest in this report.

ALAN BATEMAN.

Die künstlichen Edelsteine. By HERMANN MICHEL. 477 pages, 180 illustrations and two colored plates. Wilhelm Diebner, Leipzig, 1926. Price, 25 marks.

This book is a comprehensive presentation of the subject of the imitation of gems and precious stones, their distinction from the genuine stones, and the position they occupy in trade. The chapters on the examination of the stones are of especial interest to the economic mineralogist and geologist. Even the layman will enjoy the volume, for it is written in such a style that little knowledge of mineralogy is prerequisite for a clear understanding. This is the second edition of the book (the first was published in 1913) but it has been so enlarged and so completely brought up to date that it is almost a new contribution. The references, in particular, have been thoroughly revised and are very complete. The first chapter treats of the fundamentals of chemistry,

mineralogy, and the origin of natural minerals. The synthesis of the minerals and the apparatus used for it are described. The accompanying references are very complete. The second chapter discusses (*a*) the history and manufacture of artificial gemstones in commercial sizes and quantities and (*b*) the synthesis of gemstones too small for trade. Under (*a*) the making of artificial corundums is taken up in great detail, first the ruby, second the sapphire, and third the less well-known varieties sold as artificial "oriental" alexandrite, topaz, etc. The shades of colors, pleochroisms and easily distinguishable differences between the artificial stones and real gems are given under each heading. Under (*b*) a history of the synthesis of the diamond is to be found. The crystal structures of diamond and graphite as discovered by X-rays are given in an easily understandable way. Even equilibrium diagrams showing the probable conditions under which diamonds are formed, and those under which they are stable, are touched upon. The reviewer finds this subchapter disproportionately long. A few pages on the synthesis of beryl, zircon, quartz, and other minerals, concludes Chapter II.

The third chapter, on the distinction between artificial stones and natural ones, is long and divided into three parts. First, the methods of investigation are described. The difficult crystallography is properly dismissed after a few pages of text and illustrations. The optical mineralogy receives a fuller treatment; the reviewer could wish, however, that it were more complete. The methods for the determination of refractive indices with heavy liquids is given in detail, however, with all the necessary tables. The second part deals with microscopic criteria. The microphotographs of the liquid and mineral inclusions seen in the gems are good and numerous. They show how it is relatively easy to tell the true gems from the artificial stones which contain microscopic gas bubbles, zones of accretion (Zuwachstreifen) and cracks. The third part of the chapter is the most extensive, and contains valuable information about the behavior of the gems and their imitations in radium rays, X-rays, cathode rays, and ultraviolet light. By this behavior jewels in elaborate settings may be tested without removal of the stones from their mountings. The apparatus for these examinations are illustrated and described. Many extensive tables are added, in which the stones are arranged according to their colors in ordinary light, with the changes for the different kinds of rays listed. Another method for the exact determination of colors of stones is the spectroscopic examination, which seems to deserve more attention than it has received in the past. A table for the examination of green stones is given as an illustration of this method.

The influence of artificial stones upon the price and demand for natural stones is treated in Chapter IV. In spite of the enormous production of

millions of carats of artificial corundum per month, the demand for natural stones has not decreased. It must be borne in mind that natural stones can *always* be told from artificial ones, even though they be of the same chemical composition. It is urged by the author of this book that the public should be informed on this point by mineralogists and geologists. He believes that the terminology of artificial stones in science and in trade must be such that no mistake is possible, even for the layman. When larger natural stones are sold, the salesman should furnish with each a description giving microscopic and other marks of identification. It is a fact that each stone possesses a kind of individuality by which it is often possible to tell even the country in which it was mined.

Chapter VI. starts with a discussion of glass (strass and paste) imitation. Dubletten—stones which usually consist of a natural upper layer to which is pasted or fused an imitation of inferior material—receive brief treatment. The author also describes the methods by which the color of stones is changed so that such stones may be sold as more precious stones. A short chapter on the routine followed in the investigation of stones, concludes the book on gemstones proper. A number of examples are given which show that a fixed order of tests need not exist. The latitude will depend, of course, upon the training of the individual. The author points out that one must always begin the task with the apprehension that the stone under consideration is probably an imitation, on account of the large number of possible counterfeits.

A chapter on the origin, the raising and imitation of pearls, is added to the book. It should prove interesting reading to laymen and mineralogists. The 180 illustrations in the book are good and well selected. An alphabetical index is added. The paper and printing—large Latin type—are excellent. The cloth binding appears to be substantial. The reviewer believes that the author's style is less involved than that of many German writers. In other words, the American student will find it relatively easy to read.

JOHN W. GRUNER.

UNIVERSITY OF MINNESOTA,
MINNEAPOLIS, MINN.

A Text-Book of Mining Geology: with sections on Mine Examination and the Geology of Petroleum. By J. PARK, Dean of Faculty of Mining and Professor of Mining Geology, University of Otago, New Zealand. 5th edit., rewritten and enlarged, 364 pps., 91 illus. J. B. Lippincott Co., Philadelphia, 1927.

The author of this text-book, first published in 1906, has taken advantage of the demand for a new edition in order to rewrite thoroughly

and revise the text. Several new chapters are added, such as "Metallogenetic Epochs," "Magmatic Differentiation," "Secondary Enrichment," "Petroleum: Its History, Genesis, and Geology," that tend to broaden the field that it covers.

The introduction, dealing with general principles, has been rewritten and its content augmented. It presents, briefly and clearly, those principles that constitute the immediate background of mining geology.

The chapters dealing with the principles of ore formation are rearranged in order to bring them up to date, and more emphasis than formerly is placed upon the genetic classification of minerals, though the morphological classification is retained as a separate chapter in order to point out the two widely different points of view from which one may approach the investigation of ore deposits.

The book is concise and readable, line drawings are used to illustrate the text and many up-to-date references are cited. The reviewer considers it a very useful book in its field.

WILLIAM M. AGAR.

YALE UNIVERSITY,
NEW HAVEN, CONN.

Principles of Human Geography. By VIDAL DE LA BLACHE. Edited by EMMANUAL DE MARTONNE. Translated by MILLICENT T. BINGHAM. 478 pp. Henry Holt & Co., New York, 1926.

This posthumous work of M. de la Blache represents eighteen years of accumulation of data. Part I deals with Distribution of Population, treated largely from a geographical standpoint; Part II, with Elements of Civilization, considering tools and building material, sustenance, human establishments and the basis of civilization; Part III, with Transportation and Circulation. The volume demonstrates adequately how geologic forces have affected human geography. Certainly any geologist will benefit by reading it; in fact, it should be a part of every natural scientist's library.

Great credit is due M. de Martonne for editing the manuscript, which was left in an unarranged state. The translator, also, has played an important part in making the book easily readable.

EDWIN BINNEY, JR.

YALE UNIVERSITY,
NEW HAVEN, CONN.

Mikroskopische Physiographie der Mineralien und Gesteine. Bd. I, 2" hälfte. Die petrographisch wichtigen Mineralien. Spezieller Teil. By Wülfing-Rosenbusch. Pp. 555–814. Pl. XXI.–XXXV. Tables 17. Text figures 83. E. Schweitzerbart'sche Verlagsbuchhandlung. Stuttgart, 1927.

The final installment of the new edition of Rosenbusch's Treatise has appeared (see ECON. GEOL., vol. XXI., p. 305) completing the volume on the optical properties of minerals. An estimate of the thoroughness of the treatment may be inferred from the fact that the discussion of the triclinic feldspars occupies 79 pages. Accompanying the volume is a series of tables in which are summarized most of the distinguishing properties of 226 minerals and mineral groups. The excellent plates are particularly noteworthy. The book is unquestionably the most comprehensive treatise on the rock-forming minerals that has ever been published. It is a necessity to the geologist who specializes in the study of rocks.

W. S. BAYLEY.

West Virginia Geol. Survey, 1926. Geological Report on Mercer, Monroe, and Summers Counties, by DAVID B. REGER. 963 pp.; 64 illust.; case of geologic and topographic maps. Price prepaid $3.50. Cost for extra geologic maps: Monroe, $1.00; Mercer, 50 cts.; Summers, 50 cts. Topographic map of each county, 50 cts. each.

The report contains detailed descriptions of the geologic history, structure and stratigraphy of these counties. Petroleum, gas, coal, iron ore, manganese and building materials are described, and the physiography of the district as a whole is discussed. There are two chapters by David B. Reger on Paleobotany and Invertebrate Paleontology.

Selenium—A List of References. By M. F. DOTY. 114 pp. Published by the New York Public Library, 1927. Price, 65 cents.

This is a list of references from 1817 to 1925, arranged chronologically according to general works, mineralogy and crystallography, physical and chemical constants, electrical and optical properties, cells and their uses, industrial applications, chemistry, and patents. It is an excellent bibliography, useful to anyone desiring references on Selenium. A good Author and Subject index at the end makes it readily usable.

SOCIETY OF ECONOMIC GEOLOGISTS

The following committees have been appointed by President Ransome:

Executive Committee

H. F. Bain, Chairman
E. DeGolyer
D. F. Hewett
Ernest Howe
G. F. Loughlin
R. A. F. Penrose, Jr.
Edward Sampson
J. T. Singewald, Jr.

Nominating Committee

Adolph Knopf, Chairman
K. C. Heald
Sidney Paige

D. F. Hewett has resigned from the Program Committee, of which he has been chairman. G. F. Loughlin has been appointed to succeed him as chairman, and will choose the other members of the committee.

George H. Ashley has been appointed delegate from the Council of the Geological Society of America to the Council of the Society of Economic Geologists.

The Executive Committee decided to hold the next annual meeting of the Society of Economic Geologists with the Geological Society of America at Cleveland, Ohio, on December 29–31, 1927.

R. A. F. Penrose, Jr., has been appointed delegate from the Council of the Society of Economic Geologists to the Council of the Geological Society of America.

SCIENTIFIC NOTES AND NEWS

Percy A. Wagner, of the Geological Survey of South Africa, recently visited the diamond fields near Port Nolloth, Cape Colony.

T. H. Clark has become associate professor of geology at McGill University, Montreal, Canada.

Walter J. Browning has resigned the position of general manager in Spain of the Rio Tinto Company, Ltd.

J. S. De Lury, of Manitoba University, is making a survey of the mineral resources of Saskatchewan before assuming the chair of geology at Saskatchewan University, Canada.

E. DeGolyer and H. Foster Bain were guests of the North Pacific Branch of the American Institute of Mining and Metallurgical Engineers and the Seattle Mining Club at a joint meeting August 6.

D. Miser has been placed in charge of the section of geology of fuels of the U. S. Geological Survey. G. R. Mansfield has taken his place as head of the section of areal and non-metalliferous geology.

Sydney H. Ball has recently gone to Mexico on professional business.

F. Julius Fohs has been in Europe for several months investigating oil and potash in Italy and Germany.

E. A. Holbrook, dean of the School of Mines and Metallurgy of Pennsylvania State College, has been appointed dean of the School of Engineering and Mines at the University of Pittsburgh.

H. DeWitt Smith has been in Jerome, Arizona, on business for the United Verde Mine.

Ellsworth Y. Dougherty is in Newfoundland engaged in work for the American Smelting and Refining Company. His address is Bucans, via Millertown Junction.

J. P. Schumacher, of the Torsion Balance Exploration Company, has brought from Europe a number of new torsion balances for use in this country. Dr. Eugene Fekete, formerly assistant to Baron Eotvos, returned with him to join the staff of the company.

Warren D. Smith, of the University of Oregon, conducted a geology summer camp in the Wallowa Mountains during June and July, and in August acted as consulting geologist on the Owyhee Irrigation Project dam near Adrian, Oregon.

Frank DeWolf, formerly chief geologist of the Humphreys Corpora-

tion, is now general manager of the Border Research Corporation, maintaining his headquarters at Houston, Texas.

W. S. McCann, consulting geologist of London, now visiting Canada, has recently been investigating the bauxite deposits of the Gold Coast Colony, Africa.

A. W. Rogers, director of the South African Geological Survey, has been visiting the diamond fields at Port Nolloth, Cape Colony, and making a tour in the Northern Transvaal.

Frank Reeves, of the U. S. Geological Survey, is spending a four months furlough in exploring work in western Canada.

G. S. Loughlin, of the U. S. Geological Survey, has been making an inspection trip through the western States, and is continuing his study of the ore deposits of Cripple Creek and other districts in Colorado.

Scott Turner, director of the U. S. Bureau of Mines, has been visiting the helium-gas fields and potash drilling sites in the western States. He is now representing the Bureau at the Empire Mining and Metallurgical Congress in Canada.

E. K. Soper, petroleum geologist, has recently opened an office at 859 Roosevelt Building, Los Angeles, California.

R. C. Emmons, of the Canadian Geological Survey, is mapping a Keewatin area north of Woman River in the Patricia district, which contains iron formations and minor occurrences of gold and lead-zinc.

Eugene Haanel, formerly Director of the Mines Branch of the Dominion Department of Mines, Canada, died June 26 at his home in Ottawa.

The committee in charge of plans for the next International Geological Congress, to be held in South Africa in August, 1929, have already tentatively arranged the following excursions of interest to economic geologists: (*a*) The Witwatersrand gold deposits (to be held during the Congress); (*b*) the tin deposits and platinum, chrome, iron and magnetite deposits, including a detailed study of the Bushveld Complex (eight to ten days, to be held after the Congress); (*c*) the asbestos mines of the Barberton District.